PRODUCTION ENGINEERING

JIG AND TOOL DESIGN

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This book
is recommended by
The Institution
of Production
Engineers

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PRODUCTION ENGINEERING

JIG AND TOOL DESIGN

Compiled not only for the Jig and Tool Designer, but for all who have an interest in Production Engineering, not excluding the Engineering Designer

WITH 270 ILLUSTRATIONS

By

E. J. H. JONES, M.B.E., M.I.P.E.

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FOREWORD

BY SIR G. E. BAILEY, C.B.E., M.I.P.E., M.I.MECH.E.

Past President of the Institution of Production Engineers

I regard this book as being one of outstanding merit. It bears the hallmark of a practical man as its author, writing understandable language for those engaged on tool, jig and fixture design and manufacture as their everyday job.

Not only does it describe how to design jigs and fixtures for the principal manufacturing processes, but the designs are related to the most economical form for the production of varying quantities of an article, the author thereby showing great experience and a first-class knowledge of general shop requirements.

The sections devoted to Broach design and fixtures are unique, in that they make public for the first time in English much information which has hitherto been exclusive to a few people. This should aid in the advancement of broaching practice in this country.

The illustrations are excellent, showing clearly details which in practice have proved to be essential, but which are often omitted from other publications on the same subject. Whilst a large variety of tools are included, each section is dealt with thoroughly. The chapters on small tools, cutting, boring and broaching tools, gauges and multi-drill heads are worthy of special note, and will be appreciated by the experienced tool designer as having a direct bearing on production.

The book should also be of very considerable assistance to students preparing for examinations in Production Engineering.

It has long been the practice for certain literary groups to recommend to the public a book which they believe to be worthy of commendation as "the book of the month." I welcome the decision of the Institution of Production Engineers to recommend this book by Mr. Jones.

G. E. BAILEY.

PREFACE

THIS work is intended not only for the experienced Jig and Tool designer but for the student of production engineering and the technical college lecturer. Those readers already skilled in the science of jig and tool design will, it is hoped, find much of real value in some of the chapters. The examples chosen have been tried out and used successfully on production and can be relied upon as sound guides in relation to their respective problems. For instance, the general increase which has taken place in grinding of recent years has called for much ingenuity from jig and tool men designing devices for wheel forming. This problem has been given special attention, a chapter being devoted to both usual and unusual adaptations. Broaching also has been given prominence not only because of the intensity of the development of this branch of tooling during recent years, but because it seems obvious that where relatively large quantities are available it will be adopted in still greater measure, embodying operations as yet not attempted.

The speed with which most materials can now be machined has changed the relative importance between cutting time and loading time, i.e. the time taken to load the workpiece into the jig or fixture and at the completion of the operation, remove it. In consequence the larger quantity of work to be handled by the operator necessitates devices to reduce human effort. A chapter has, therefore, been devoted to air operated equipment.

An effort has been made to make the work as complete as possible, touching most branches of the subject but excluding press tools which must be left to the specialists. It is hoped that the engineering executive, no matter in what position, may benefit from a careful reading and will, in consequence, be better able to make quick and accurate decisions, more readily realise what tooling programmes imply and be, in the execution of his duties, more comfortable and certain than the man without this knowledge.

The rapid development which has taken place in recent years in the design of tools, jigs and fixtures, has widened the adaptation and increased the productive capacity of the standard machine tool and raised the potentialities of the plant in every engineering organisation, the tooling department of which is controlled by one having knowledge of modern tooling application and the vision to adopt and adapt to the plant he is engaged in equipping. Such a company is fortunate and may quite probably obtain results equal to that obtainable by large capital expenditure on new plant.

Purely mass production examples and photographs of special purpose machines so prevalent in a work of this kind have been avoided in order that the contents may be of greater interest and value to engineering generally. Whilst of necessity the commencement of some of the chapters has had to be of a simple nature, extremely elementary examples are not general because it is considered that the reader will already have some knowledge of the principles of production and of the primary machines.

The writer wishes to emphasise and acknowledge the help received from A.E.C. Ltd. in the shape of numerous examples of their practice.

E. J. H. JONES, M.B.E., M.I.P.E.

PREFACE TO SIXTH EDITION

AN example of the equipment required for transfer machining on a workpiece requiring a substantial number of operations has been included in this edition. This might well be described as something more than a half-way stage between the usual operation on a single machine and complete automation. Included also is an example of recent achievement in the process of deep-hole trepanning.

PREFACE TO SEVENTH EDITION

IN this edition, the opportunity has been taken to include information on ceramic cutting tools which have been successfully used in many production operations and on most metals with increased metal-removal rates and reduced costs.

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Chapter I

FUNCTION AND ORGANISATION OF THE JIG AND TOOL DEPARTMENT

IT is not intended to explain all the functions of the departments relative to engineering organisation except in so far as the jig and tool department operates in collaboration. Such reference is, however, briefly necessary in order that the position occupied by the department responsible for jigs and tools is appreciated. The extent of the organisation necessary will vary in proportion to the size of the works in which it is installed. In a very small undertaking it is possible to visualise one man performing all the duties of the tool department. The following, however, is a brief survey of the organisation generally adopted.

When the management of a concern decides which type of mechanism or assembly is to be manufactured, the decision, if not made in conjunction with the chief engineer, is conveyed to him. It then becomes his responsibility to provide the designs and carry out what experimental work may be necessary. His arrangement drawings are then handed over to the chief draughtsman, who distributes certain units among his staff, whose duty it is to make detailed drawings of each individual piece, on which should be all the information required by the factory to produce the piece, including the whole of the dimensions, particulars of material and heat treatment, also including the limits to which certain parts are to be made and the finish required.

Typical Component Drawing

The example shown in Fig. 1 is a typical component drawing and has three symbols only to denote the class of finish required. These three symbols are those most generally used, probably adequate for the component depicted, but it is quite likely that on many components insufficient information is thereby conveyed to the works. It cannot be overemphasised, however, how important it is that all the available information in connection with finish is added to the component drawing.

Class of Finish

A more detailed and specific list of symbols might well be as that which follows and is to be recommended :

G—Ordinary good-class commercial grinding finish.

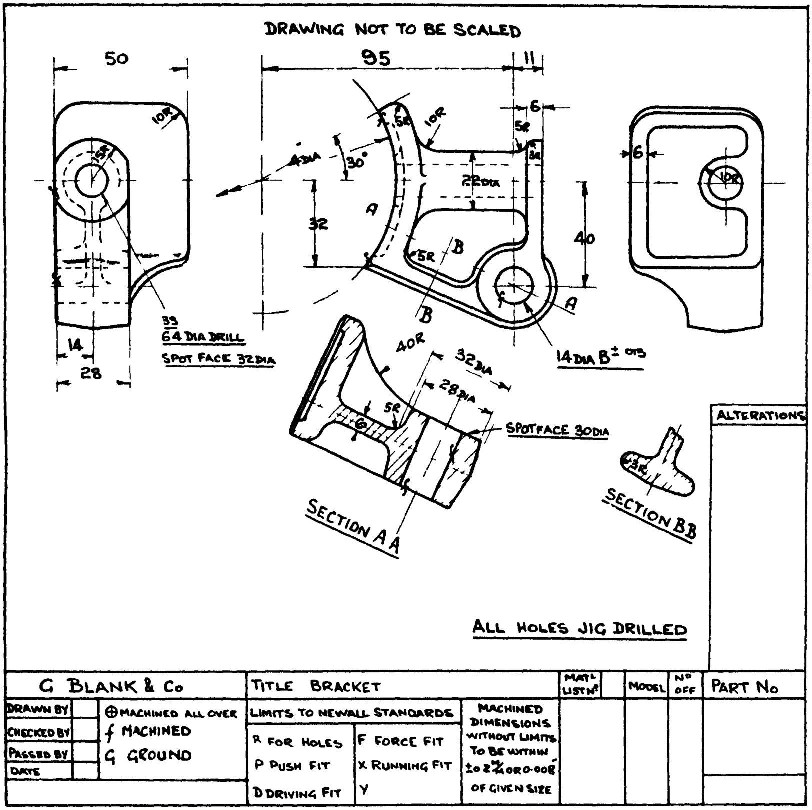


Fig. 1.—A TYPICAL COMPONENT DRAWING

GG—Grinding without chatter or wheel marks, applicable where necessary, to surface or face grinding.

F—Ordinary machining finish.

FF—Fine machining finish.

FFF—Machining finish without tool marks, leaving the works the alternative of finishing by grinding. Any finer finish than indicated above should be mentioned on the drawing—such as lap or hone, etc.

Making the Layouts

The work of making the layouts, the general principle of which is shown in Fig. 2, is often done by what it known as the planning depart-

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OPERATION AND TOOL LAYOUT						PART Nº Z240	
DESCRIPTION. BRACKET. MODEL N F.				MATERIAL (ALUMINIUM) DIE-CASTING			DATE
OPER Nº	OPERATION	M/C SYM	DEPT	TARGET TIME HRS	TARGET TIME MINS	FIXTURES, TOOLS, GAUGES.	ALTERATIONS
1.	MILL FLAT FACE ONE SIDE (CUTTING FEED 6" PER MIN)	VMC	KLM		2	FIX Z240-1A	
2.	DRILL REAM AND FACE COMPLETE	RDC	KLM		5	JIG Z240-2A PLUG GAUGE SL 780 REAMER SL 790 DRILL SL.760	
3.	BORE 4" DIA TWO CUTS (220 REVS PER MIN. FEED 32" PER MIN ROUGHING 40" PER MIN FINISHING)	CMA	N		1	FIX Z240-3A (4 AT A TIME)	
4.	BURR AND STAMP	SLAB	KLM		1		

Fig. 2.—EXAMPLE OF A TYPICAL LAYOUT

ment. This department not only plans the work by making operation layouts of each piece, but schedules the work so that from the times against each operation any particular machine's commitment can be determined maybe months or even a year ahead. From the schedules thus compiled, it is possible for the production engineer to ascertain whether sufficient plant will be available for the work in hand, or whether or not some machines will be over or under committed.

Importance of Collaboration

Before going further into the actual work done by the jig and tool department, it is necessary to emphasise how essential it is that the men who prepare the layouts do so in close collaboration with the jig and tool

draughtsmen because, obviously, the draughtsman, who has to lay out jigs and fixtures so that the locations on one operation are taken in such a manner as to satisfy the next or subsequent operations, sees the job in far greater detail than the man making the layout. Many firms have their layout department adjacent to and often under the same chief as the jig and tool department, and this arrangement is to be commended. When the reverse is the case and the two departments are apart and under separate heads, it is quite usual for a large proportion of the layouts to be changed to meet difficulties or needs discovered during the laying out of the jigs and tools.

Personnel

The jig and tool department is usually composed of a jig and tool superintendent, chief draughtsman, leading draughtsmen and draughtsmen, tool cost estimator, record clerks, tool-room foremen, in whose charge will be jig-boring machines, good-class lathes, shapers, planers, drilling machines, surface grinders, plain and internal grinders, universal grinders, tool grinders, cutter grinders, tool fitters, toolsmiths, hardening shop, and also the main tool storekeeper and sub-tool storekeepers.

The Object of the Jig and Tool Department

The object of the department is primarily that of reducing costs and ensuring that interchangeability which allows for rapid assembly, and also speeding up machine times by eliminating handling and setting of the component parts by the production machine operators.

The principle of making components interchangeable is not new, and to bear this out we may mention that well over 100 years ago a firm received an order for a batch of guns on which each part or unit could be dismantled from any gun and assembled to any other gun. Among the earliest of manufacturers to commence production on the lines of interchangeability were the makers of sewing machines and Swiss watches. One of the principal reasons for this step was the avoidance of tariff duties on the completely assembled article, which did not apply if the goods were assembled in the purchasing country.

Selective Assembly System

It should be understood that to obtain true interchangeability on good-class work may prove a very expensive procedure, since this may mean splitting hairs on many operations where it is not really necessary to do so. A principle adopted on some components is to employ a system of selective assembly. By this system components are machined to tolerances which can be worked to economically, but which may be too wide for efficient assembly, and then to correct the fault by selecting components for assembly together to give the required fits.

Tooling

Nevertheless, tools are required whichever type of manufacture is wanted, whether for quantity alone or a combination of quantity and accuracy. During the past twenty years the engineering workshops have been able to employ fewer and fewer skilled workmen, chiefly because the use of jigs and fixtures and the repetitive nature of quantity production have lessened the opportunity for training. Jigs and tools, therefore, are taking the place of the skilled man in the production factory, and making it possible to employ unskilled or semi-skilled operators in his stead.

Tooling equipment ensures also that uniformity of finished product which could not be expected otherwise, because of the variation of skill between individuals. Tools ensure that the same piece of work is done in exactly the same way, with precisely the same result and maintain coincidence of performance between individuals, especially from the point of view of interchangeability. This position can be seen to the greatest extent in the largest mass-producing organisations.

It has become no longer possible to place orders for small quantities in such factories, because so much expenditure in special plant and elaborate tools is required that it becomes economically imprudent and thoroughly unsound as a commercial proposition. The large manufacturing concerns using expensively tooled elaborate special-purpose machine tools, operated by semi-skilled or unskilled labour, are being forced to equip separate small works for producing experimental models and the first few hundreds of their products, before they are handed over to the mass-production factory. The smaller works are equipped with general-purpose machines manned by more skilled operators using simple and inexpensive jigs and fixtures, or by skilled men using the primary machines without special tooling.

The rapid development in tooling which has taken place during the last few decades, particularly in works producing large quantities, has brought about a change in the amount of work done at one operation. Whereas the skilled operator was often called upon to do a large number or even all the operations required to produce the piece, the tendency now is for a component to be split up into a large number of mostly simple operations, with a different machine and operator performing each separate operation.

It has been found economical also to reduce the operations, as far as possible, or even alter the equipment to bring each separate operation to a like time basis, in order that the flow of material through the works may be regular and unimpeded and so preventing a short-time operation having to wait for an earlier operation taking a longer time. A further advantage is that the material can be kept on the move until it is assembled, instead of occupying space on the shop floor. It will be realised how much such an arrangement can be organised by preplanning, coupled with a thorough knowledge of tooling possibilities.

"Tooling Up"

The expression to "tool up" a component means to design and supply all jigs, fixtures, cutting tools, and gauges required for the manufacture and inspection of the piece, including any structural alterations to machine tools which may be found necessary. Cams for operating automatic machines may be required, formers for profiling machines, and so on. In fact, on occasion when the quantities warrant it, the jig and tool man is called upon to design special machinery. It is, therefore, advisable that not only has he had a thoroughly practical training in workshop operations and principles, but also that he has a good general knowledge of mechanical movements and proportions, and it is recommended that he makes a close study of gearing and gearing problems.

A rudimentary knowledge regarding the practical application of the laws relating to pneumatics and hydraulics must also be considered part of his stock in trade. His scholastic training will, of course, include applied mechanics and mathematics.

Nomenclature

The range of work passing through the jig and tool office comes under a number of headings, many of which will be dealt with later, but at the outset it is essential to appreciate what is meant by a template, a jig, or a fixture.

Template

This is a piece of sheet material shaped to the same profile as the piece to be fabricated and is used as a guide for the blacksmith to hammer a part to the required shape. A template may also be to the shape of a component, but in addition have holes drilled through it in similar positions to those required in the finished pieces. This type of template is then placed over the pieces to be machined and the position of the holes marked by a scriber through the holes in the template, so eliminating the time which would otherwise be required to mark off each individual piece.

A further type of template may be made from gauge plate and hardened. It can be clamped in the vice alongside the work piece, which can then be easily filed to the same form. This method is often used when quantities are small, to prevent expenditure on costly formed cutters. All types of templates are used to save time when quantities are small or there is no money available for more expensive equipment.

Jig

This may be described as a plate, metal box, or structure on to or into which components can be clamped in identical positions one after the other. Holes are bored in the structure, so that when tools are fed through them and into the component, holes are made in the component in the correct positions as required by the component drawing, the holes in the jig positively locating and guiding the cutting tools.

Fixture

This may be described as a structure holding and locating a component or work piece in a definite position, the cutting tools being set in position by gauges, trial-and-error, and machine adjustment. As against the jig, the fixture does not positively locate the cutting tools. A fixture is bolted or fixed to the machine table, whereas with a jig this is often unnecessary.

The Allocation of Work in the Jig and Tool Drawing Office

This should be placed under the following headings :

(1) Cost estimating.

(2) The design of equipment for new parts.

(3) The redesign or alteration of equipment necessitated by design alteration or layout change.

(4) Records.

Estimating or Costing Section

This section of the jig and tool drawing office may, in small works, be non-existent except in the person of the head of the department, who will make his own estimates. In the larger concerns this work should be done by the same men because experience over long periods is essential for accuracy.

The estimates should be computed in some detail, i.e. cost of patterns and material, and hours of work required to manufacture reduced to terms of money by the hourly rate paid in the tool room. This section should be responsible for allocating the work either to the tool room or sources outside the works. If from experience gained either in connection with quality or price, it is decided that the work shall be placed in the factory's tool room, then the number of hours allocated to the work is conveyed to the tool-room foreman. The estimates can serve as a basis for a bonus system. If it is considered more convenient that the work be placed with outside firms, an excellent check on the prices charged is available.

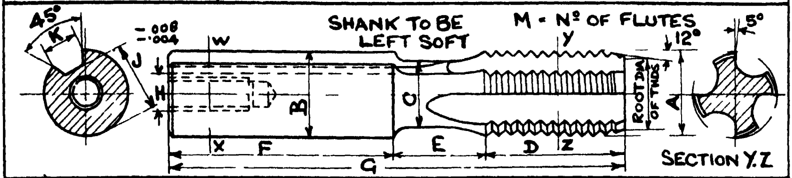
This department should always watch the cost of tools made, and so check deviations from the estimates. These estimates are of inestimable value, not only in order that the management may know, before tooling work is started, to what extent they will be committed, but also to the chief of the jig and tool department, who is able to see at a glance the progress made on any " tooling-up " programme by an examination of that proportion of the value used against the total allocated.

New Design

In that section allocated to the design of new equipment, it is advisable that the same man is given the same sort of components to tool up, so that the experience gained is cumulative. This man will be responsible

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JIG & TOOL STANDARD LIST



INDEX Nº	MARK TAP DIA	TPI	HAND	A	B	C	D	E	F	G	H	J	K	M	SIZE OF TAPPER	HEAT TREATMENT
1																MATERIAL HIGH SPEED STEEL SCLEROSCOPE HARDNESS Nº 75-85 LIMITS ON EFFECTIVE DIA: 0 - ½ DIA NOMINAL TO +·001 9/16-1 " +·0005 " +·002 1 1/16-1½ " +·001 " +·0025 1 9/16-2 " +·0015 " +·0035 OVER-2 DIA +·002 " +·004 MAXIMUM PITCH ERROR ALLOWED ·0005 PER INCH OF THREAD LENGTH
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																

MACHINE TAPS STANDARD WHIT THREADS	MATERIAL	SHEET 1 850

Fig. 3.—STANDARD TOOL SHEET

for the whole of the equipment on these parts, and if the work is of a lengthy nature, he will rough out the designs only, and pass these to detailers working under his supervision, finally checking their work when completed.

Alterations

In the third section referred to, much of the work is of a routine nature, but, because of its varying character, should be in charge of a competent all-round man. Yet because of the frequent trivial changes made, which nevertheless involve the search for, and examination of, drawings, and investigation into equipment already made, this section serves as an excellent training ground for juniors and apprentices.

Records Section

The records section is an important one and will be responsible for maintaining lists of standard tools, such as reamers, milling cutters, taps, dies, boring and turning tools, etc., which may be stocked in the tool stores even though these may not be to recognised national standard dimensions, but have been necessitated by the peculiar requirements of the works. From these standard sheets, an example of which is shown in Fig. 3, this section will check the possibility of using existing tools on new programmes and so prevent duplicate ordering or the creation of new and possibly unnecessary tools.

The Importance of Accurate Dimensioning

The importance of the care which must be taken in filling in dimensions on standard sheets cannot be over-emphasised, and unless the draughtsman is convinced that the new tool he proposes to add to the list is in approximately the same proportion as the tool shown at the head of the sheet, he should draw his new tool roughly to the correct scale before adding dimensions to the standard list. The following true story will amplify this necessity. During the war of 1914–1918 a firm of aero engine builders, now defunct, required taps for sizing the threads on the ends of crank-cases. The thread was approximately 4 in. diameter by 16 threads per inch. A draughtsman filled in the dimensions on the standard list to exactly the same proportions as had been previously allocated to taps ranging from $\frac{3}{16}$ in. up to $\frac{5}{8}$ in. dia. and, as was the normal practice in the works, one gross of taps was ordered. The weight of each tap was approximately 43 lb., yet several were made before the error was discovered.

THE JIG AND TOOL DESIGNER VERSUS THE ENGINEERING DESIGNER

The engineering designer, the man responsible for the new design to be manufactured, cannot, because it is not his particular job of work, be as familiar with the scope and limitations of modern machine tools as the man who has to equip them and get the best out of them.

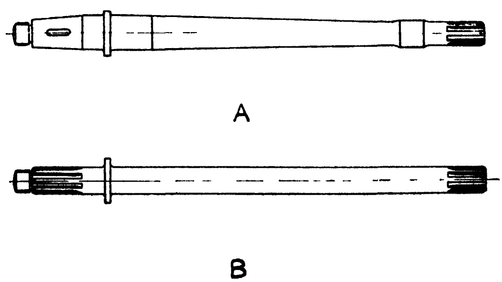


Fig. 4.—Shaft design

A, shaft designed for correct stress loads ; *B*, shaft designed for cheap production.

Parts are consequently often conceived and draughted to such a shape as to puzzle the tool man to produce them. It may be that the part has been designed to correct engineering principles, may-

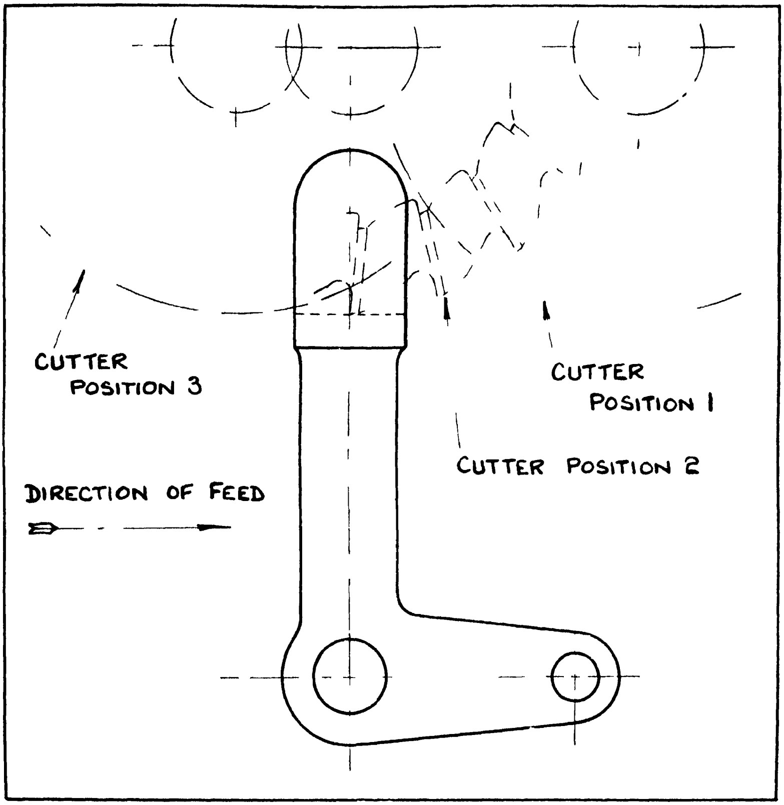


Fig. 5.—FORK-ENDED LEVER WITH BOTTOM OF SLOT SQUARE

be the shape has been arranged to avoid the concentration of stresses; such being the case, the ingenuity of the jig and tool department must be mustered to provide the tools to machine the part to the required shape.

An Example of Axle-shaft Design

The following example will emphasise and make clear this point. In Fig. 4, design *A*, is a drawing of an axle shaft, subject to bending and torsional strain, designed as closely as practicable, in accordance with the law of uniform stress. Design *B* is the same shaft made in accordance with the dictates of cheap production. The material and labour cost of design *A* was originally about 33 per cent. greater than design *B*, for which shaft standard machines and tools are adequate; whereas for shaft *A* form tools are required for the radii adjacent to the ball-race fit, and some

special taper-turning equipment wanted for tapering the shaft throughout its length. Although originally objecting to being called upon to produce a shaft to the shape of *A*, because of the extra cost involved, the tool department finally produced it for the same cost as *B*, by designing special and rather elaborate automatic taper-turning equipment. This is an example showing how collaboration and effort have produced a better and stronger article at no greater cost to the purchaser, the extra cost of equipment being negligible when spread over the quantities required.

And now to review the opposite side of the picture—those instances when the jig and tool man is justified in calling the attention of the design department to unnecessarily expensive production. At the same time it should be borne in mind that the engineering department must have the last word because they should have a greater knowledge of correct engineering design than the production man, who in his turn should know more of the possibilities of the machine shop. And because the engineering department's knowledge of the realities of the machine tools is often of the vaguest, it should be part of the recognised work of the tool man to object to designs which are unnecessarily wasteful of machining time, or in other words, parts which are expensive to produce when a change in some detail would cheapen or simplify the product without altering its effectiveness.

A Fork-ended Lever

The following are a few examples emphasising the point in question :

Fig. 5 shows a fork-ended lever. The bottom of the slot in the fork end is shown flat and square with its length. To produce this the milling cutter has to traverse through the slot to machine the bottom of the slot flat. Now, if the bottom of the slot was made a radius as would be produced by the periphery of the milling cutter used for the operation (*see* Fig. 6), the length of traverse would be considerably reduced, it being no

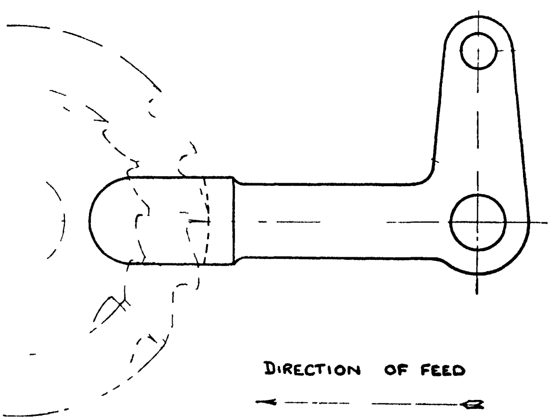


Fig. 6.—FORK-ENDED LEVER WITH BOTTOM OF SLOT RADIUSED TO SUIT CUTTER

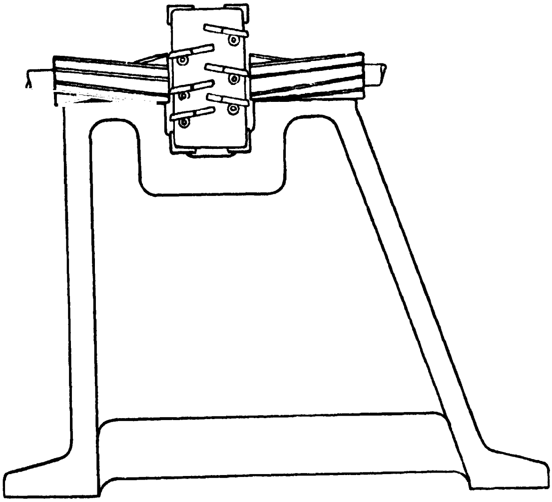


Fig. 7.—GANG MILLING BEARING BLOCK SEATING

more than the depth of the cut. A further important advantage is obtained in that to perform the operation as designed, the fixture holding the component would be designed to accommodate the component in a vertical position. If the piece was of any length it would be more difficult to obtain rigidity than would be the case if the slot had a radius at the bottom. All that would then be necessary is a fixture high enough to permit of the cutter clearing the machine table, and the cutter, by means of the longitudinal traverse fed straight into the slot.

Fig. 7 shows how a joint face and several bearing-block seatings, can be gang milled simultaneously in a casting because the ends of the case have been kept open by the designer. Many such components are ribbed across at the ends, making gang milling impossible.

A Common Fault

A common fault is that of specifying a full thread to within a small dimension from a shoulder or calling for a full thread right up to a shoulder. Fig. 8 shows a spline shaft the plain portion on which is to accommodate a ball race. It will be realised that in order to cut the thread on the screwed end, particularly when using a die-box, a lead is required on the dies and therefore sufficient distance from the end of the full thread to the shoulder is necessary to accommodate this lead. The dimension A should be as long as possible, and if it is required that strength be

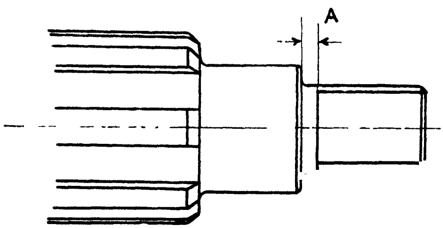


Fig. 8.—CLEARANCE FOR DIE WHEN SCREWING

provided in the corner, undercutting need not be resorted to, and a small radius may be specified.

A Gear-cutting Error

In Fig. 9 we have an example of an error often prevalent. The accompanying drawing shows a cluster gear, the smaller gear of which can only be cut by the shaping method because the lower face of the gear is too close to the larger gear to permit of hobbing. This being the case, sufficient clearance between the two gears must be allowed in order that the cuttings have room to drop away beneath the shaping cutter. One method of doing this is to recess the lower gear as shown in the diagram and wash away the chips with the cutting lubricant, but where it is impossible to form such a recess, then the dimension between *A* and *B* could be increased and should never be below ¼ in. This dimension, although all too small, is often more than designers admit they can accommodate.

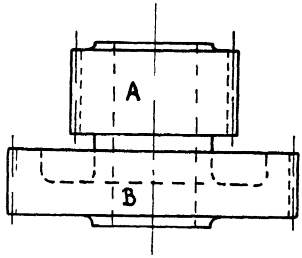


Fig. 9.—Clearance for Gear-shaping Cutter

A Casting Design Fault

Fig. 10 depicts one side of a large casting on which three faces have to be machined at various heights. This is a common designing fault and a costly one. The production man has these alternatives : he can arrange to keep the machine set at the correct height for one of the faces and put the batch of components through, milling one face on each, then altering the setting of the machine and repeating the process for the second and third faces (by this method the component has to be handled and located three times), or the component can remain on the machine and the cutter setting be changed to suit the three dimensions required. This latter method may, in some cases, prove the faster, but, owing to the difficulty of continued accurate re-setting of the cutter, is certainly more conducive to scrapping work.

It is usually a simple matter for the designer to arrange such faces

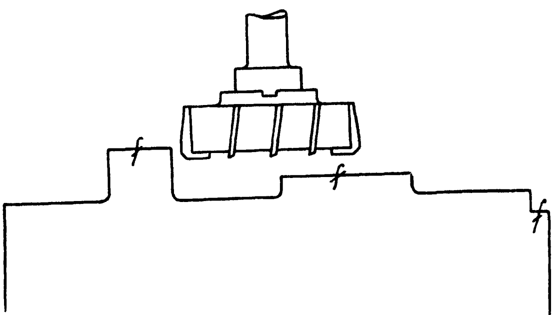


Fig. 10.—Machining Faces at Various Heights on Castings

in line so that they can be machined at one setting.

Another Common Error

Fig. 11 shows an example of another common error on the part of the designer. The two holes shown in line are too far below the top face of the casting to be drilled with any degree of accuracy from a bush plate clamped above, and are also too close to the wall to allow room for guide bushes to surround them, thereby enabling them to be jig drilled.

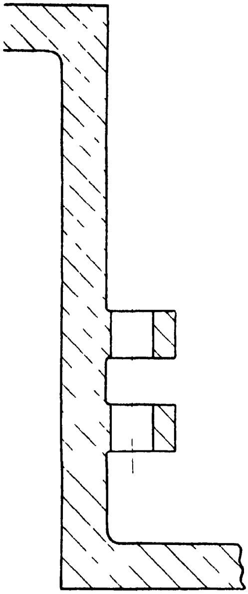


Fig. 11.—An example of bad design

Variations from Accepted Standards

The tooling department must also watch for variations—emanating from the design department—from the already accepted standards in use in the works, and also, where possible, indicate where national standards can be adopted. The reasons for the former is that new tools will be required, with consequent capital outlay, and also the tool stores must carry replacements, with the result that larger sums of money than necessary are tied up in tools not actually earning. In the latter case, national standards should be adopted where possible, because tools of this nature can usually be purchased from stock often more cheaply than special requirements. Screw threads, splines, gear teeth, the sizes of reamed holes, etc., are particularly prone to these variations.

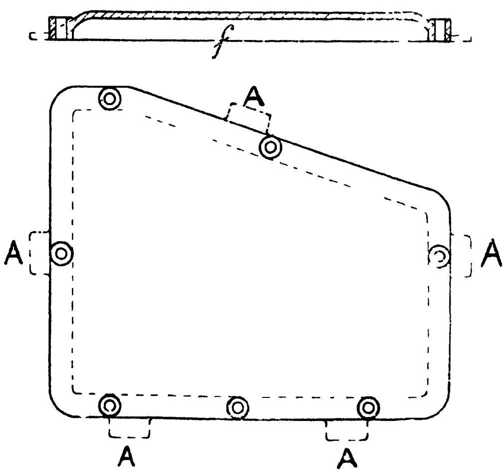


Fig. 12.—The provision of clamping lugs (*A*) on a flimsy casting

Clamping Lugs

Care must also be taken to make certain that the lugs or bosses required for holding the component whilst being machined are added

when necessary in the right places.

In Fig. 12 is an example of a casting, the flimsy nature of which renders it almost impossible to hold in a vice without undue distortion. The lugs which have been provided at *A* serve as places on which the component can be clamped and, on the underneath surfaces, points at which the component can be located. The lugs are removed after machining the face marked *f*.

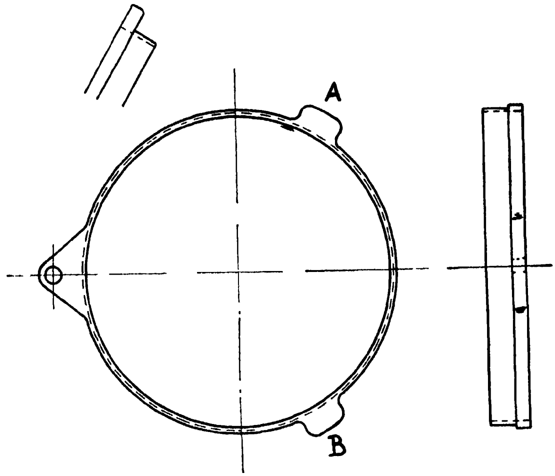


Fig. 13.—THE ADDITION OF TWO LUGS (*A* AND *B*) TO BE USED FOR CLAMPING

The steel ring, Fig. 13, is too fragile to be chucked in the normal manner. In the finished article, only the one lug with a hole through it is required ; it is therefore necessary to add two further lugs to facilitate holding without causing distortion, the two lugs being cut off after turning.

The casting in Fig. 14 would require quite an elaborate fixture for it to be satisfactorily held and located for the boring, screwing, and facing operation. With the addition, however, of a small boss, an extension to the casting, the holding can be done in a chuck without the use of special equipment. The casting in question is aluminium and the boss in this instance has proved adequate. Should, however, the same problem arise in iron

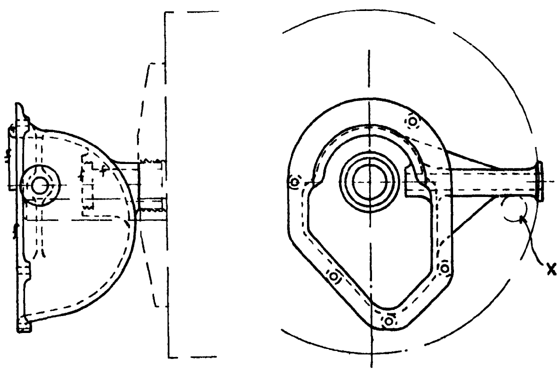


Fig. 14.—CHUCKING BOSS ADDED TO FACILITATE BORING AND FACING

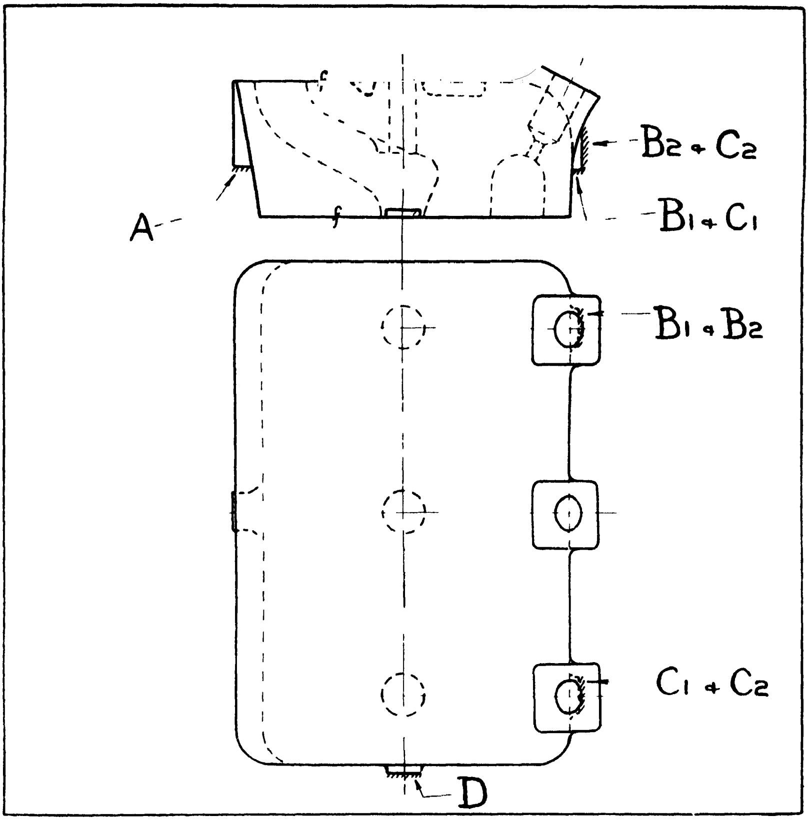


Fig. 15.—" SPOTTING POINTS " USED FOR LOCATION DURING MACHINING

or steel, a driving pin would be required, as shown at *X*, so that the load from the cut is not taken entirely on the chuck jaws, the long boss on the component resting against the pin and serving as a driver. The chucking boss is removed after boring.

" Spotting Points "

One of the most important precautions to be taken is that of the provision of " spotting points." These are represented by small areas of a size to suit the nature of the component from which the founder is prepared to guarantee the cored parts of a casting to be accurate. They are consequently points from which the casting can be viewed when delivered into the works, and, furthermore, form positions against which the piece can be located in its first operation fixture.

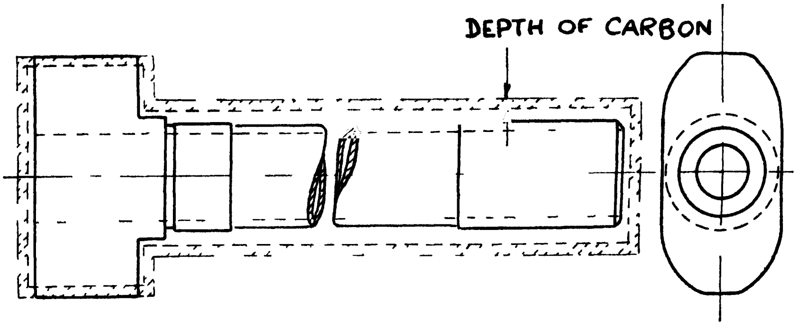


Fig. 16.—REMOVING CARBON AFTER CARBURISING
Shank and sides of cam to be left soft.

This avoids the use of expensive adjustable parts in the fixture, with the consequent loss of setting time.

These points should only be determined in collaboration with the foundry and should be in such positions that they are accessible and can be adjusted by filing or grinding by the founders to equalise or correct errors through distortions occurring when the casting is cooling, or through fault in the foundry procedure. The casting depicted in Fig. 15 illustrates the value of these spotting points which, in this instance, have been arranged to serve for two operations. When milling the top face of this component, the casting is raised on the positions *A*, *B*1, and *C*1. It can therefore be assured that when the holes are subsequently drilled in the three bosses standing above the joint face, they will be central with the bosses, because the founder has taken care that the bosses are cast in the correct relative position from the three spotting points mentioned above. After the opposite face has been machined, the drilling operations take place. The locations for lateral and longitudinal positions are taken from *B*2, *C*2, and *D*. Also, as all the cored positions in the casting should be in the correct relative position from all the above points, all subsequent drilling, counterboring, or other type of machining should be accurate and reasonably central with the surrounding material.

Carburised Components having Portions left Soft

Drawings of stampings must also be scrutinised to ensure that, on parts requiring casehardening when a portion is to be left soft, there is sufficient material available, in the required position, for the carbon to be removed following the carburising process. In some cases, instead of removing carbon by a machining operation, copper plating is resorted to in order to prevent the carbon gases from penetrating the piece. When this method is adopted there is, as a rule, no need to add extra material to the component, the copper plating being removed by grinding

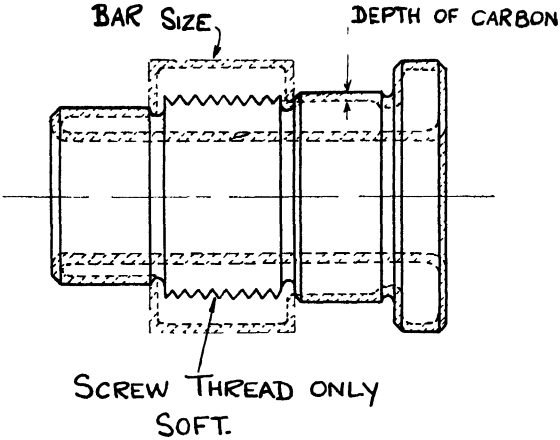


Fig. 17.—REMOVING CARBON AFTER CARBURISING
Thread to be left soft.

only where the part is required to be hard.

Alternatively, the parts of the component to be subsequently hardened can be protected in the coppering vat by an insulation, which generally takes the form of rubber caps.

Copper is not wholly satisfactory as a protecting medium because of the difficulty of depositing copper in bores and on sharp corners, such as are met with in or on splined parts. During transport and handling generally, coppered surfaces can easily be damaged and the copper displaced, with the result that carbon penetration is possible locally and hard spots are prevalent after hardening.

The component shown in Fig. 16 is an example of a part the shank of which has to be left soft together with both faces of the cam on the end. The whole cam profile, however, has to be hardened. The jig and tool man should ascertain, therefore, that there will be sufficient metal on the shank diameter of the stamping, so that after the carburising operation a cut can be taken along this diameter and the carbon removed. On the outside face of the cam this precaution is not required, because the draw required for stamping will allow for sufficient metal for subsequent removal. The operation sequence would be :

Turn diameter of shank to suit cam-milling machine collet chuck and to leave for removal of carbon.

Cam mill to size.

Carburise.

Turn, leave for grinding and face to length, leaving sufficient for a finishing cut (removing carbon from all faces required soft).

Heat treat to harden.

Finish bore and face to length.

Finish grind diameter.

The part in Fig. 17 is an example of a bush requiring a soft thread between two hardened and ground diameters, with a hardened and ground bore. The operations are as follows :

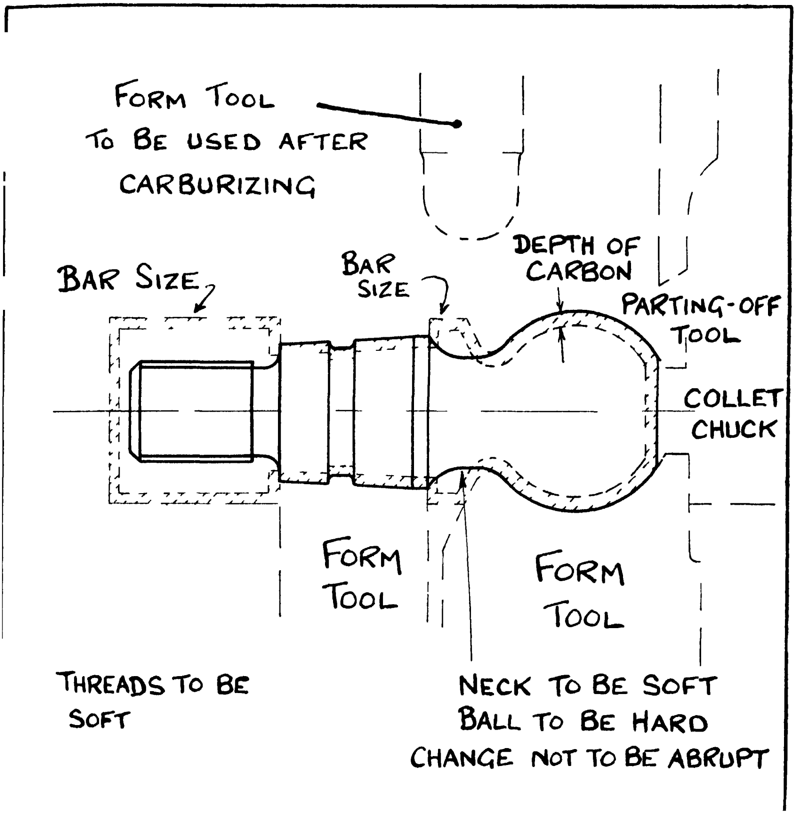


Fig. 18 —Removing carbon after carburising
Thread and Neck to be left soft.

Turn three diameters and face to length, leaving thread diameter bar size ; leave bore size for grinding.

Carburise.

Turn to remove carbon

Heat treat to harden.

Grind bore.

Finish turn and screw thread.

Finish grind two diameters.

In the example shown in Fig. 18, whilst there is no need to leave extra material on the component in the rough state, over and above the bar diameter from which the piece is made, it is still the jig and tool man's

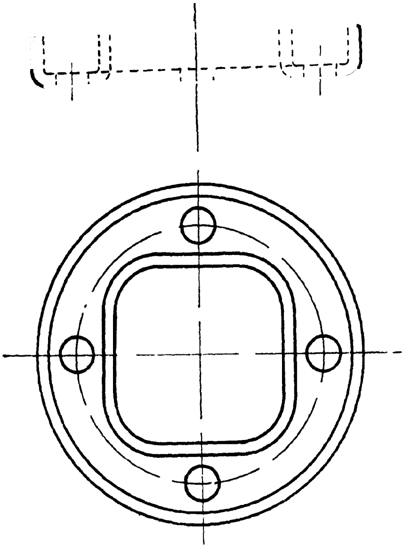


Fig. 19.—PRESSING TO HAVE FOUR HOLES DRILLED

responsibility to arrange, as in this case, his form tools in the first operation, so that metal is left on where required, and provide for the subsequent removal of carbon, where necessary. In the illustration described the neck of the part in question is subjected to considerable bending load and shock. This portion must, therefore, be left as ductile as possible. On the ball portion, however, considerable wear has to be resisted, and this surface must therefore be hard. By use of the form tools shown in the diagram, this effect is achieved, and the result is further improved because the tools are of such a shape that there is no abrupt change from the carburised to the uncarburised section, so preventing a concentration of stress at this position. It will be seen that the result will be the hardened or carburised portion gradually fades out because of the radius arranged on the first tool.

THE ECONOMICS OF TOOLING

The economics of tool engineering is as important as the design of the equipment itself and is a question, for the most part, of simple arithmetic or business courage and foresight.

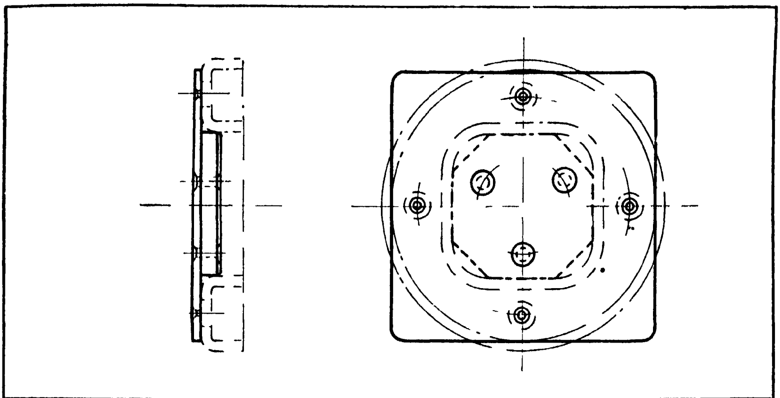
When the quantities to be machined are definitely known, the savings which can be made by providing special labour-saving tools can be calculated.

The pressing (Fig. 19) has four holes which have to be drilled in correct relation one with another. Let us examine the economics attached to four of the different ways in which this operation could be tooled.

We will assume for the purpose of our calculations that the cost per minute of labour and establishment charges in the works drilling this piece is 1*d.*

Method 1.—*Operation—Drill Holes without Special Tackle*

Mark off	5 mins.
Drill	4 mins.
	9 mins. @ 1*d.* per min. = 9*d.* each.



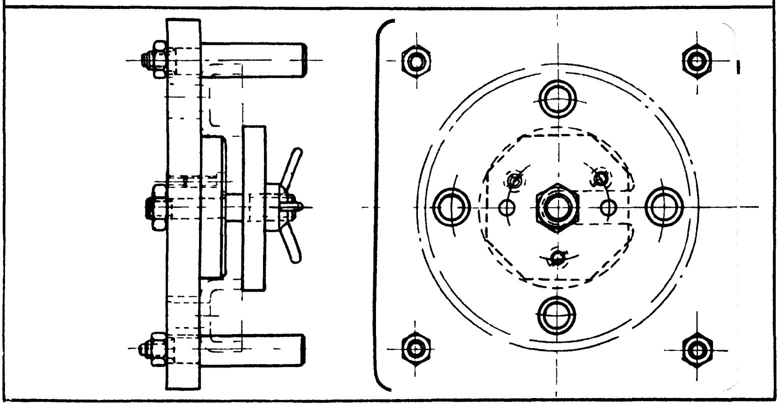


Fig. 20 (TOP).—TEMPLATE FOR MARKING OFF FOUR HOLES

Fig. 21 (BOTTOM).—DRILL JIG FOR FOUR HOLES

Method 2.—*With Template for Marking Off* (*Fig.* 20)

Cost of template . . . . £1 0*s*. 0*d*.
Mark off . . . . 2 mins.
Drill . . . . 4 mins.

6 mins. = 6*d*. each.

3*d*. saved on each component will pay for the cost of the template if 80 are machined.

Method 3.—*With Drill Jig* (*Fig*. 21)

Cost of jig, say . . . . £8 10*s*. 0*d*.
Load in jig and drill 3 minutes or . . . . 3*d*. each.
6*d*. saved on each component will pay for cost of jig if 340 are machined.

Method 4.—*With Multiple Drill Head and Self-aligning Jig* (*Fig*. 22)

Cost of head and jig, say . . . . £55 0*s*. 0*d*.
Drill all four holes simultaneously—1 min. or . . . . . 1*d*. each.
8*d*. saved on each component will pay for equipment if 1,650 are machined.

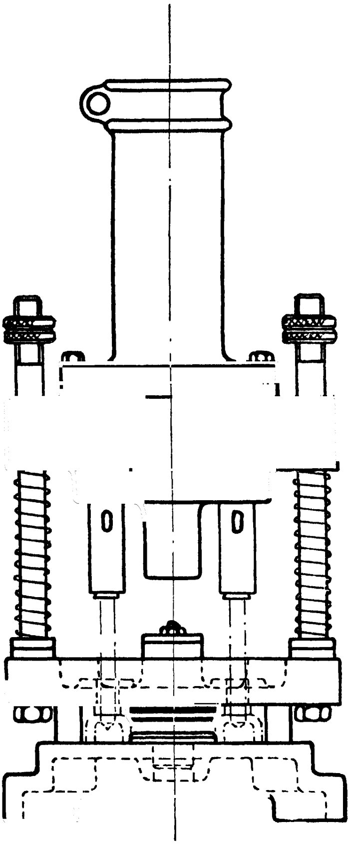


Fig. 22.—Multi-drill head and fixture for four holes

With the foregoing figures available, and knowing the quantities to be machined, the problem can be solved by simple arithmetic. For instance, suppose we assume three different quantities may be required 20, 800, and 10,000.

By the Method 1—20 will cost 15*s*. It is therefore not worth while spending £1 0*s*. 0*d*. on a template as Method 2.
By Method 2 -800 will cost 6*d*. each, plus £1 0*s*. 0*d*. = £21 0*s*. 0*d*.
By Method 3—800 will cost 3*d*. each plus £8 10*s*. 0*d*. = £18 10*s*. 0*d*. It therefore pays to make the jig as Method 3.
By Method 3—10,000 will cost 3*d*. each, plus £8 10*s*. 0*d*. = £133 10*s*. 0*d*.
By Method 4—10,000 will cost 1*d*. each, plus £55 0*s*. 0*d*. = £96 13*s*. 4*d*.

The foregoing figures are self-explanatory, but when quantities are unknown and can only be determined by assumption, assisted perhaps by market estimates, business courage and foresight and confidence in your product are required.

Other considerations have, on occasions, to be included in tool-policy deliberations—such as the quality and skill of the labour available and the amount of elaboration and "fool-proofing" required in the tools for satisfactory results to be obtained.

Also the time for completion or the delivery date of finished parts may necessitate the duplication of tools. Or again, it may be necessary to speed up the machining by more expensive tooling and show a smaller profit in order to free the machine tool for other work, and so avoid the necessity for purchasing expensive additional plant, or alternatively obtain the output required from the plant already installed.

A further example of tooling economics in which other factors are involved is as follows :

Assuming it is required that the flange shown in Fig. 23 has to be

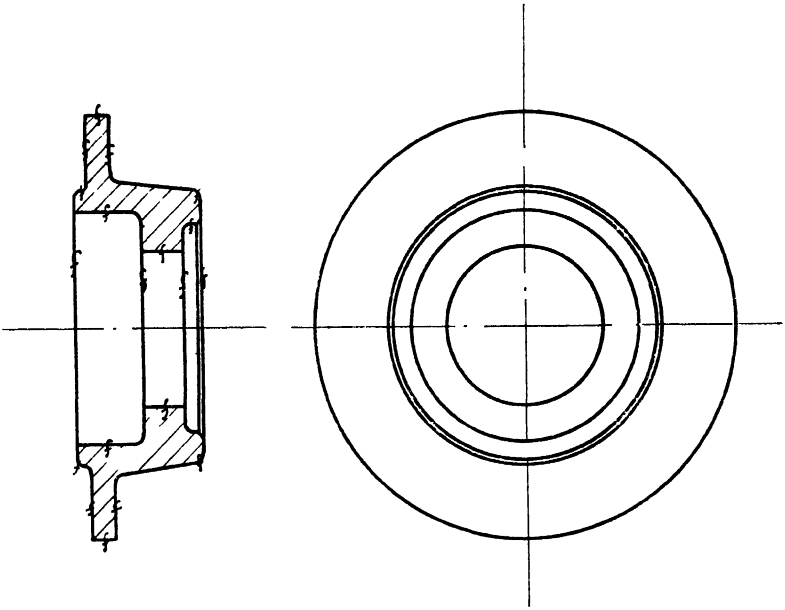


Fig. 23.—FLANGE TO BE MACHINED WHERE MARKED *f*

machined all over, with the exception of the outside diameter of the tapering portion. In relation to the quantities involved, three alternative methods, providing that the plant was available, might be considered, namely :

1. Turning all over on the engine lathe.
2. Machining in two operations on a combination turret.
3. Tooling up the part for the two operations on a chucking automatic in order that two or three machines may be tended by one operator with or without assistance in loading the machines.

Assuming again the cost of labour and overheads to be 1*d.* per minute, the alternative times and costs would be somewhat in proportion to the figures given below :

Method 1.—*Engine Lathe—use Standard Existing Tools*

Time for turning both operations on one only, 4 hrs. = £1 0s. 0*d.*

Method 2—*Combination Turret Lathe—Number required,* 50

Operation 1 (Fig. 24).—Chuck on tapered diameter and rough and finish both sides of flange ; turn outside diameter and register ; form larger bore, and bore smaller bore	33 mins.
Operation 2 (Fig. 25).—Face to width, chamfer, bore, and counterbore second inner face	16 mins
	49 mins.

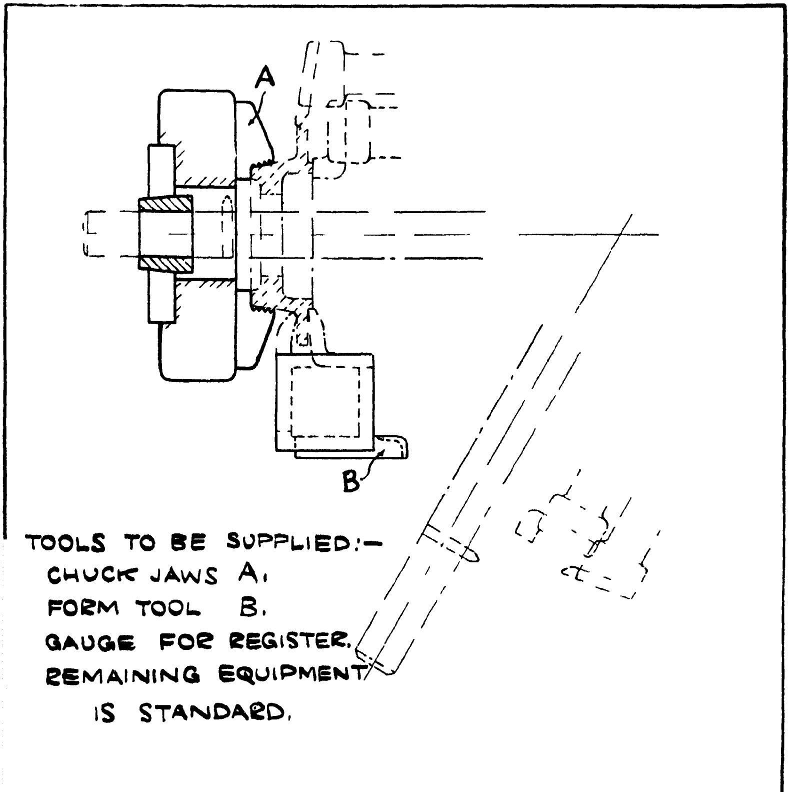


Fig. 24.—COMBINATION TURRET LATHE, FIRST OPERATION

	£	s.	d.
Estimated cost of tools	20	0	0
Setting up time, say, 3 hrs. @ 1*d*. per min. .		15	0
Actual labour and overheads 49 mins. @ 1*d*. per min., 4*s*. 1*d*. per piece, 50 off	10	4	2
	30	19	2
Saving over Method 1 for 50 = ...	19	0	10

Method 3.—*Chucking Auto with Air Chuck. Number required,* 1,000
Operations exactly as Method 2, but the time would be :

Fig. 26, 1st operation	30 mins.
Fig. 27, 2nd operation	16 mins.
	46 mins.

One operator would probably work two or more machines with or without unskilled assistance according to the system of the shop. If we take as our example that of one man working two machines, the cost of labour and overheads on each machine might be per hour, 2*s*. labour, plus 3*s*. on each machine, resulting in a figure of 4*s*. per hour, or ⅘*d*. for each machine per min.

	£	*s*.	*d*.
Estimated cost of tools	60	0	0
Setting-up time, 6 hrs. @ full rate 5*s*. per hr. . .	1	10	0
Cost in labour and overheads per piece ⅘*d*. at 46 mins. = 36⅘*d*. per piece, 1,000 × 36⅘*d*. . . .	153	6	8
	214	16	8

		£	*s*.	*d*.
Cost of 1,000 by Method 1 . .	=	1,000	0	0
Cost of 1,000 by Method 2 . .	=	224	18	4
Cost of 1,000 by Method 3 . .	=	214	16	8
Saving of Method 3 over Method 2	=	10	1	8

The figures above on Method 3 are assuming that the 1,000 are run off at one batch. If the batch is broken, subtract from the saving £1 10*s*. 0*d*. for each batch to cover the cost of machine breakdown and set-up.

The foregoing is intended as an example of tooling economics only, and not as a specimen of the allocation of overheads. The figures in such calculations must, of course, be those ruling in the works.

It should be borne in mind that, having decided upon the jigs and fixtures to be used and the design and type of cutting tool and gauge to be employed, consideration must be given to continuity of production. It would be of little use providing complete equipment with but one cutting tool of each type only. Such items of equipment must be purchased in sufficient numbers to avoid delays when worn tools are being ground or to take the place of tools broken or used in service. In the case of a hob or broach many weeks are necessary for replacement, and the wise executive will see to it that his production is not stopped for any of the foregoing reasons.

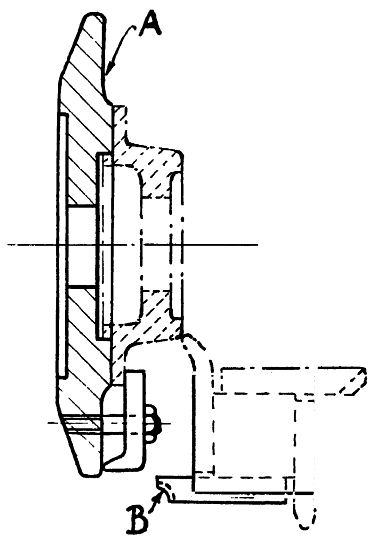


Fig. 25.—Combination turret lathe, second operation

Tools to be supplied: Fixture *A*; radius tool *B*; gauge for limit bore. Remaining equipment is standard.

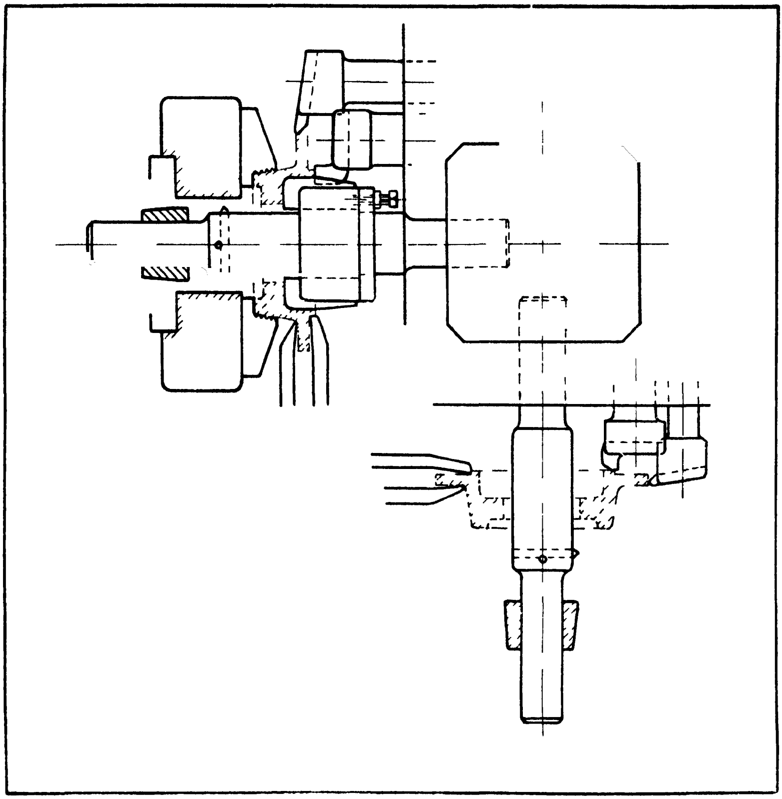


Fig. 26.—Chucking automatic with air chuck, first operation

The quantity of each tool ordered will depend very much upon the type of operation and the quantities ultimately to be machined without alteration. The larger the quantity which it is felt can be ordered at one time, the better prices are likely to be obtained. It would be false economy, however, to over-order when the work pieces are likely to be subject to design change or to be limited in quantity. Decisions have therefore to be taken in relation to such eventualities. If the accuracy required is not extreme, then form tools, for the sake of economy, may be left in the " as hardened " condition with no subsequent form grinding; but if the reverse is the case and fine accuracy cannot be obtained due to distortion likely to take place when hardening such tools, then grinding

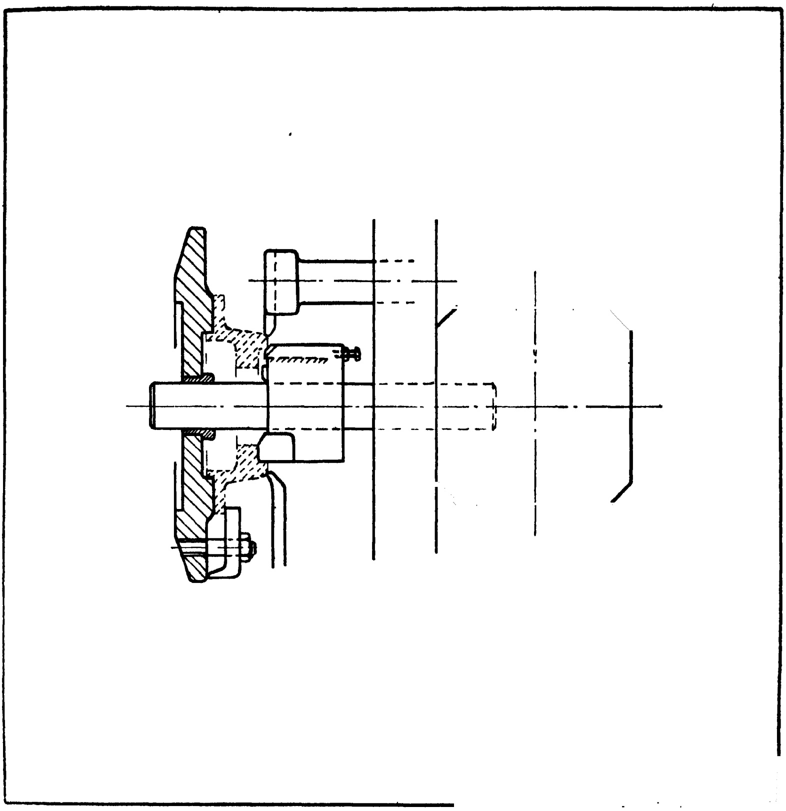


Fig. 27.—Chucking automatic with fixture, second operation

of the profile must be resorted to. Gauges also, where the tolerances are fine, must be themselves made to within closer tolerances at increased cost.

Consideration must be given also to what proportion of the cutting tools, or gauges for that matter, ordered at the onset are to be charged to capital account and what proportion will be carried in the normal overheads of the organisation. It might well be that only such tools as are required to start production are considered as capital expenditure, to be ultimately written off or charged away over a predetermined quantity of the product.

Chapter II

FITS AND TOLERANCES

IT is recorded that about the end of the seventeenth century a man named Wilkinson constructed a machine which would bore a cylinder to such accuracy that, after inserting the piston, not more than one shilling could be placed into the gap between the cylinder wall and the piston. Although this fact may appear ludicrous in the light of present-day accuracy, the difficulties encountered by the builder of this early machine were undoubtedly very much greater than those met with by makers of the highly accurate machine tools we now use.

In addition to producing parts dimensionally accurate and interchangeable in a factory, we may now, by the use of standard gauges, intermingle components produced in various factories in different parts of the country. Furthermore, because of relationships which have been established between the standards applying in different countries, dimensional agreement is now possible between engineering organisations throughout the world.

Limits

No scheme of manufacture is likely to be successful without the adoption of a limit system and the practice of working to limit gauges in order to define, and " tie up " with certainty, variations from standard and productive error. It is not only in interchangeable and repetition work that these advantages are felt, but the reliable efficient service obtainable from a well-controlled limit system, where gauges are periodically checked at intervals in proportion to the amount of their use, can be an advantage in all engineering enterprises—as indeed they are to a very great extent.

Definitions

It is advisable at the outset to be clear as to the meaning of the expressions relating to tolerances and fits.

Allowance

This is a variation of dimensions so determined that various types and qualities of fits are obtainable.

Tolerance

This is the amount of the difference from a required dimension laid down in order that unavoidable imperfections in workmanship can be tolerated.

Unilateral Tolerance

This is where both the maximum and minimum dimensions are together above or below a basic figure—as :

$$1 \text{ in.} \begin{matrix} + \cdot 002 \\ + \cdot 001 \end{matrix} \text{ or } \begin{matrix} + \cdot 001, \\ + \cdot 0 \end{matrix} \quad 1 \text{ in.} \begin{matrix} - \cdot 001 \text{ in.} \\ - \cdot 002 \text{ in.} \end{matrix} \text{ or } \begin{matrix} - \cdot 0 \text{ in.} \\ - \cdot 001 \text{ in.} \end{matrix}$$

Bilateral Tolerance

This is where the maximum and minimum dimensions are respectively one above and one below a basic figure—as 1 in. $\dfrac{+ \cdot 0015 \text{ in.}}{- \cdot 0015 \text{ in.}}$

An Interference Fit

The term " interference fit " is used where the mating parts have to be assembled by pressure, or, in other words, there is fouling between the smallest shaft and the largest hole.

A Clearance Fit

This is a term used where there is definite or positive clearance between the largest shaft and the smallest hole.

Limit

This word is self-explanatory, but is perhaps more generally used in place of " tolerance " than should be the case. It would be more correct to use this word only in the more general sense, such as when referring to a particular limit system, or the extreme dimensions prescribed in order to allow of various qualities of fits.

Hole Basis

Hole basis is used when referring to that particular system of limits where holes are given fixed tolerances relative to their diameters, but the tolerances on shafts are varied to obtain the kind of fit required.

Shaft Basis

This is the opposite of hole basis. In this case shafts are given fixed tolerances, the holes being varied to provide the fit required.

Classification of Fits

There are various standardised systems of tolerances, each varying basically, but all providing allowances or tolerances which permit of mating parts either clearing each other, revolving or sliding one within the other, or interfering, so that they have to be either pushed, driven, or forced to effect assembly. Because it is the oldest and most universally used in this country, let us examine the Newall System, which is on hole basis and is bilateral.

Although, now generally recognised as inadequate for all modern requirements, this system has served British industry well for many years. (Reference is made later to the B.S.I. standards).

Hole Tolerances

In this system the various allowances are known by symbol letters. For holes, two classes or qualities are arranged—A and B. The choice of which of the two is adopted by the user is dependent on the quality or fineness of accuracy required in the product. Class A is the finer of the two—for instance, on a 2-in. hole the tolerance is $\frac{+ \cdot 00075}{- \cdot 00025}$, representing a total tolerance of ·001 in., whereas on class B the dimensions for a 2-in. hole are $\frac{+ \cdot 001}{- \cdot 0005}$, with a total tolerance of ·0015 in. Consequently, work can be passed to class B with a 50 per cent. greater margin for error than A.

Shaft Tolerances

Running Fits are divided into three grades :

Class X for easy fits where sufficient room for lubrication is required, or running clearance when parts have to run a high temperature.

Class Y for good average machine work.

Class Z for fine instrument and tool work generally.

On 2-in. shafts the tolerances are :

X =	− ·00175		
	− ·0035	tolerance	·00175
Y =	− ·00125		
	− ·0025	,,	·00125
Z =	− ·00075		
	− ·0015	,,	·00075

Push Fit, class P. Shafts made to these limits will not be free enough to rotate unless force is used, when they will quickly seize.

Driving Fits, class D. Shafts made to these limits will require driving into their respective holes.

Force Fits, class F. Shafts to these limits will require more pressure than that applied for class D, and parts so made can only be mated under a press.

Too much space would be required in this section if tables of tolerance were included. The foregoing references only are considered necessary.

It cannot be expected, however, that any system of limits will be adequate to cover every case arising, but all systems have been devised from much accumulated experience and have generally proved their suitability for almost all everyday operations. The remainder must be

arrived at by trial and error in the organisation in which they are required, after consideration of the material, shape, length of bearing, and probable conditions arising, in order to determine the tolerances for initial experiments.

Choice of System

In choosing a limit system, various considerations have to be studied in order to determine what already standardised tables of tolerances and allowances are applicable and which selections from them are likely to meet requirements. These considerations can be classified as :

1. Cost and Facility of Manufacture

The wider the tolerance chosen, the cheaper and easier will it be to produce the article. Fewer stoppages of the production machines will result for the purpose of changing and regrinding tools. Tools, such as reamers, taps, core drills, etc., will last longer before becoming undersize, and, further, more wear can be allowed on gauges than would be possible with fine tolerances. Gauges can therefore remain in service longer without replacement—a big consideration on a costly article.

2. The Length of Life of Moving Parts

The decision taken in this case will most likely rest on whether it has to be made up to a standard of good quality or down to a price. For instance, a cheap vehicle or machine is, at the end of four or five years, ready for the scrap heap, but an expensive and well-made article can be relied upon for many more years.

Wear in the parts of the cheap machine at the end of, say, four years may be no greater on its wearing parts than a few thousandths of an inch. It must be remembered, however, that the more a part has worn, the faster will it wear further. Without being manufactured to a standardised limit system, pieces of machinery made many years ago can still be seen running satisfactorily, because each part was made and fitted perfectly, to function correctly one part with the other, with the finest clearances that time and workmanship could produce. This practice was equivalent to fixing individual tolerances and allowances for every mating part. Most of the work being done by " hand " methods, and cost not being the main consideration, few gauges were required. It should be the aim, as far as possible, to obtain similar fits by production methods, by a judicious selection from standardised limit systems. A correct selection of tolerances will not alone, however, increase the " life " of moving parts. Some firms manufacturing a cheap article specify the tolerances to which the work is produced, but as little consideration is given to the quality of the finish the parts wear quickly. The wearing surfaces are reduced by reason of the roughness of the machining cuts, both the gauging and the wear being taken on the " high " spots only.

3. The Correct Functioning of the Article

Care must be taken that lengthwise tolerances are not such as to produce unnecessary end play, which, in machine tools particularly, would result in indifferent finish or inaccurate work.

For parts keyed on to shafts, fine tolerances must be chosen and care taken in selection, because too tight a fit may result in bursting a part or too slack a fit may cause it to become loose in operation, with the possibility of disastrous results. Study carefully the extremes of tightness and slackness resulting from parts being made to the maximum and minimum of these conditions within the chosen tolerances. Having chosen a set of limits for the article to be produced, the gauges must be regularly examined and maintained if quantities are to be manufactured.

4. The Cost of Tools or Gauges for the Installation of the System Chosen

The system of tolerances and allowances already installed in a works whether a hole or shaft, unilateral or bilateral basis, will, in many instances, due to the heavy cost of installing a new system, be the deciding factor ; but where a new system has to be adopted, or it is possible to make a change, the national standard on the hole basis with unilateral tolerances is to be recommended. Such a system is that issued by the British Standards Institution in their report No. 164 of 1924. The system is sound and is arranged so that holes are kept to standard dimensions, and by putting the fitting allowances on the shafts, the number of reamers, floating cutters, etc., to be stocked are kept to a minimum, to say nothing of the requirements in " Go " and " Not go " plug gauges for holes necessitated by the shaft basis system. Gauges for shafts can be made adjustable and can be " set " with slip gauges, but gauges for holes cannot be satisfactorily accommodated in this way. There are, it must be added, however, still many protagonists for the shaft-basis system.

5. Quietness and " Feel " of the Article when Working

Noises in machinery are annoying to the purchaser, the operator, and all who come in close contact with it, and should be controlled as far as possible. It may be difficult to control sound emitted by hammer blows, escaping steam, or exhausting air, but slack machinery and fitting can produce sound equally disturbing. In the case of gear teeth, inaccuracies from the true involute or spacing of the teeth can produce most distressing whines. No set tables or tolerances can be consulted to cure this trouble, which is only the result of inaccuracy. These and similar instances will always create individual problems, yet all are solvable by setting limits of accuracy.

For instance, it can be expected that a normally stressed gear will run quietly, providing the deviation from the true involute form on the teeth is not more than ·0002 in. and there is no greater combined error from tooth to tooth of form and spacing than ·0004 in.

Even when limited to the above errors, a gear may still be noisy, due to error within these tolerances occurring on each tooth in the same place. This will produce a regular high periodic vibration, resulting in a whine unpleasant to the human ear. By way of contrast, certain gears for aero-engine superchargers are so highly stressed that variation from true involute to the extent of ·002 in. is required, because of tooth deflection caused by the load applied.

It will be realised, therefore, that all problems cannot be solved by a standardised limit system, and that for certain conditions much experimental work may be necessary. Again, if ordinary running fit tolerances were imposed between the crankshaft and its bearings in an internal combustion engine, particularly of the compression ignition type, seizure would take place in a very short time because, from its compactness and high compression ratio a great deal of strain is created in the crankcase and working parts.

An example of the limits in such a case is that the diameters of the bearing journals of the crankshaft are finished to a nominal size $\begin{matrix}-\cdot 002 \text{ in.} \\ -\cdot 001 \text{ in.}\end{matrix}$ whilst the bearings are finished to nominal size $\begin{matrix}+\cdot 0025 \text{ in.,} \\ +\cdot 002 \text{ in.}\end{matrix}$ so giving a maximum clearance of ·0045 in. and a minimum of ·003 in. Such clearances are found to be necessary to maintain the most perfect bearing when the engine is running under load and with a force feed lubrication system.

Chapter III

GAUGES

WHEN suitable tolerances for a product have been determined, the next thing to consider is how best they can be controlled and maintained. The two primary influencing factors are the types of gauges selected and the machine tools available.

Accuracy Obtainable from Machine Tools

Grinding.—A very large quantity of production work is now finished to size by grinding, and the tolerance within which work can be finished by this method must bear some relation to the size of the work. External grinding of parts up to 2 in. diameter can be easily finished in quantities to a tolerance of ·0005 in. by means of one of the grinding gauges on the market, which indicate the size of the work whilst it is being ground, although it is claimed for an automatic measuring device for grinding machines based on a photo-electric cell that accuracy to within $\pm$ ·0001 in. can be obtained automatically.

Centreless grinding can, on suitable components, be controlled to $\pm$ ·0001 in. Internal grinding can be kept within $\pm$ ·0003 in. of size, and for exact work, by slowing down the output somewhat, within $\pm$ ·0002 in.

Automatics and Turret Lathes.—In auto and turret-lathe work, external diameters can easily be controlled within $\pm$ ·001 in., and in certain cases to closer limits. For internal work, small holes can be kept within $\pm$ ·00025 in. and larger holes within $\pm$ ·0005 in.

Milling.—Parts which have to be gang-milled can be kept within a tolerance of ·001 in.

Broaching.—Broached pieces may be relied upon to a few ten-thousandths of an inch.

Shaping and Planing.—Shaped or planed parts, although not usually called for to a high degree of accuracy, may be turned out to limits ranging from ·001 in. upwards, according to size.

Fine Boring.—The latest high-speed boring machines, equipped

with tungsten-carbide tools, using fine cuts and chiefly used for cast iron, should maintain size to within ·0002 in. or ·0003 in.

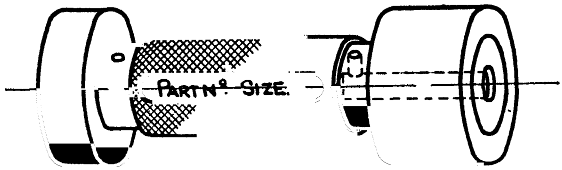


Fig. 1.—Internal-limit plug gauge

Diamond Boring.—The high-speed diamond boring machines used for light alloy and non-ferrous materials will produce component parts to within ·0001 in.

Machine tools of a high order of excellency can now be obtained, but many firms fail to get the best out of them by using faulty work-holding devices, which often distort the part outside of the limits required. It is important, therefore, when designing fixtures to consider this feature and take steps to prevent such faults.

STANDARDISED TYPES OF GAUGES

The next consideration is the standardised types of gauges.

Internal-limit Gauge

It will be observed from Fig. 1 that the lengths of the two ends, which are the gauging portions, vary. The reason for this difference is that in all cases the longer end goes into the hole, whereas the shorter end must not enter. These are known as the " Go " and " Not go " ends. This type of gauge is the most widely used and is usually termed a plug gauge. When gauging blind holes, i.e. holes having no outlet to the air except where the hole breaks through the one face of the work, it is essential to provide an air vent in the plug gauge, otherwise it is not possible to pass the " Go " end of the gauge into the hole, especially if it happens to be a close fit.

Fig. 2 is a gauge of similar type, but being used for a large-diameter hole, the weight has been reduced by a circle of holes drilled through each end; also, to reduce the cost of the material from which the gauge is made, it

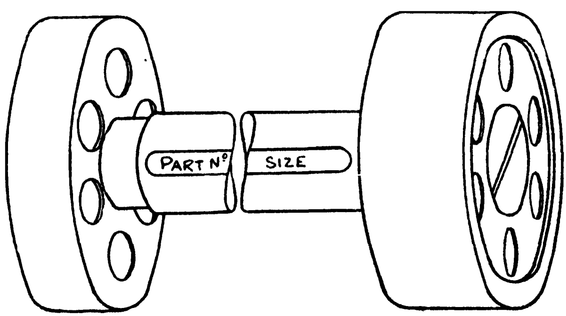


Fig. 2.—Internal-limit plug gauge for large bores

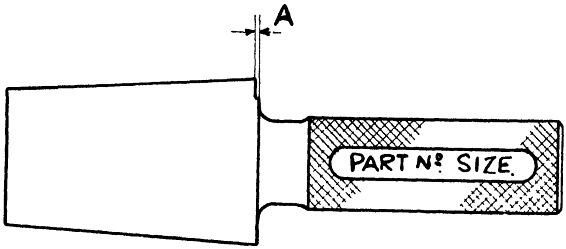


Fig. 3.—Internal-limit taper gauge

has been made in three pieces instead of from bar material, as Fig. 1.

Internal-limit Taper Gauge

Fig. 3 shows an example of a limit gauge for taper holes. A double-ended gauge is, in this instance, unnecessary because the difference in diameter between the high and low limit of the tolerance can be converted into a lengthwise dimension representing the amount that the largest diameter of the gauge may stand " proud " from the taper hole when the largest diameter of the hole is made to the low limit of the tolerance. In the example shown the taper is 1 in 8 on diameter, the difference between the high and the low limit being ·002 in. The difference in gauge position measured along the axis equals ·016 in. A flat is therefore ground on the gauge equalling this dimension at *A*. The hole is consequently within the tolerance when, on inserting the gauge, the large diameter of the hole falls between the end of the gauge and the shoulder produced by the flat.

External-limit Gauge

The gauges almost universally used for external measuring are similar to that shown in Fig. 4, which is a Wickman gauge, although there are many variations of the principle on the market, these being known as adjustable gap gauges. Not only can this gauge be adjusted for varying allowances around a nominal dimension, but can be set anywhere within the range which the gauge accommodates. For instance, a 2–2½-in. gaugecan be set anywhere within and around these two dimensions. A multiplicity of gauges for external diameters is by this method avoided.

This gauge has two fixed anvils on one jaw and two adjustable anvils on the other jaw, so that two pairs of measuring faces are available. The front pair are set to the " Go " or larger dimension of the tolerance and the rear pair to the " Not go " or smaller dimension. Correct work will pass between the front anvils, but will not pass the rear pair. These anvils must, of course, be set by accurate gauges, and for this purpose most firms rely on standard-end measuring bars.

Standard-end Measuring Blocks (or Gauge Slips)

These bars (see Fig. 5) are so calibrated that combinations when " wrung " together will provide practically every commercial tolerance required. They can be purchased to guaranteed dimensions within 2-millionths per inch of length for reference work, 5-millionths for inspec-

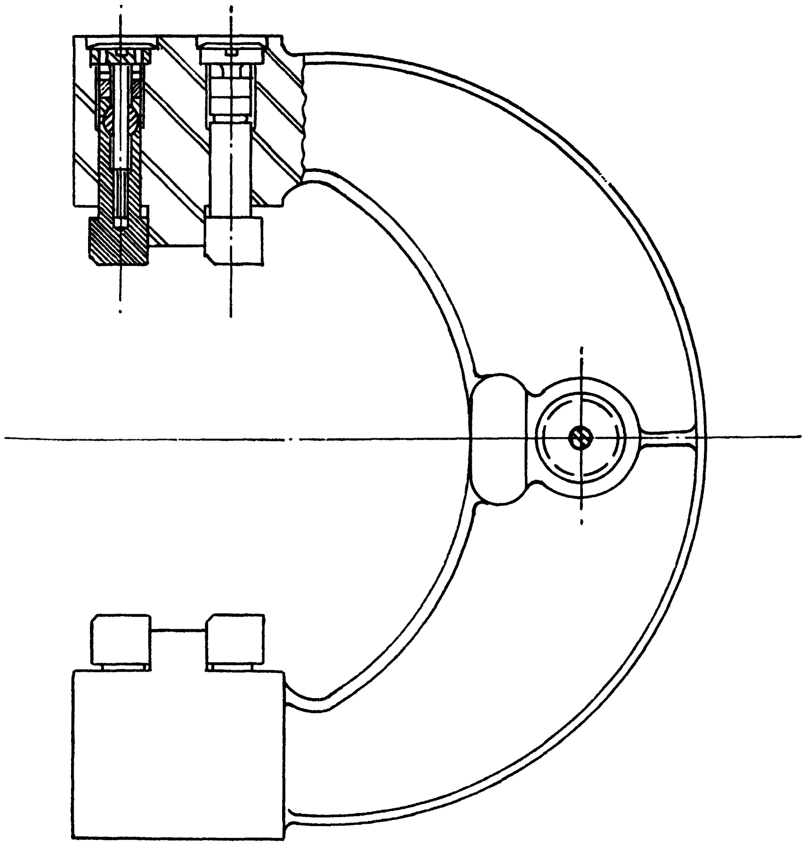


Fig. 4.—ADJUSTABLE EXTERNAL-LIMIT GAUGE

tion, or one hundred-thousandth for ordinary shop use where they may be used for general purposes, such as setting calipers, comparing sizes, testing for parallelism, or, when slightly worn and used with care, for setting cutting tools.

When the numbers of like external limits used in a works are small, but the quantity of components on which these are used is large, time in gauge setting can be saved and the possibility of error avoided by the use of limit reference bars.

Limit Reference Bars (or Sectional Plug Gauges)

The bars are usually made from flat section material (Fig. 6), one edge being divided by a sawcut, on one side of which will be the high and

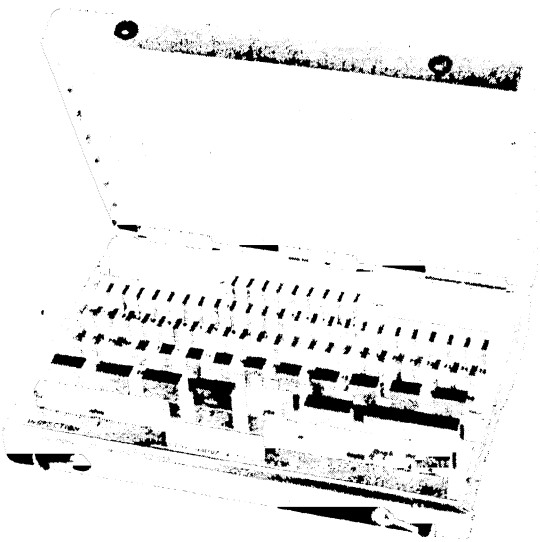


Fig. 5.—SET OF STANDARD SLIP GAUGES
(*By courtesy of Coventry Gauge and Tool Co., Ltd.*)

on the other the low dimension of the tolerance. This type of gauge is also fairly widely used instead of selections from standard-end measuring blocks, and is often made with the gauging surfaces ground as part of a cylinder; this has the advantage of allowing the gauge to be used for limit bores, and it is possible to determine whether the hole be round or otherwise by applying the gauge in various positions.

Standard Reference Bars

These are used for general reference purposes and are usually purchased to the nominal dimension, but sometimes have high and low reference sizes (Fig. 7).

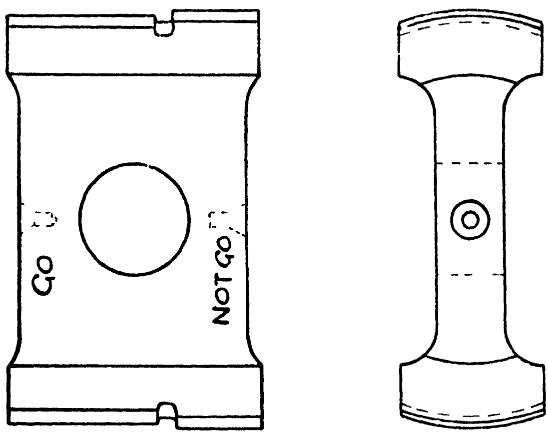


Fig. 6.—SECTIONAL PLUG GAUGE

The gauge makers will guarantee accuracy to within plus and minus ·00005 in. of the nominal. This gauge is perhaps most usefully applied when the tolerance on the work is too small to permit the use of the micrometer or the adjustable-limit gauge in the usual manner.

The size of the

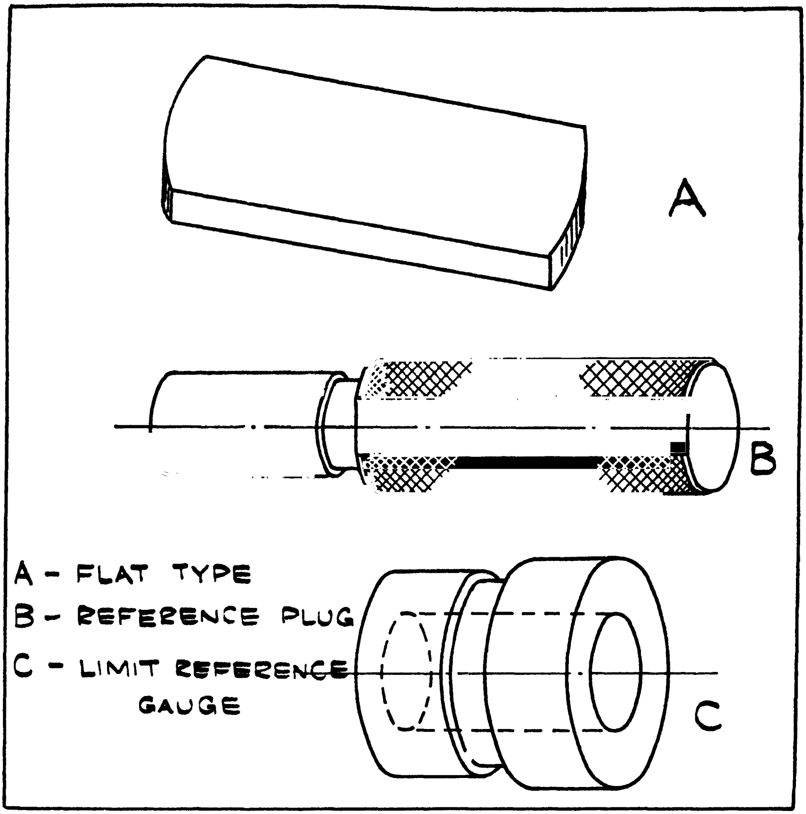


Fig. 7.—REFERENCE GAUGES

work is determined by comparative "feel." The micrometer or external measuring gauge is set to the reference bar and the work machined until the gauge passes over with resistance equal to that encountered when the gauge is passed over the reference bar. These reference bars are made in various forms—in flat section with two opposite edges forming a segment of the diameter, as single-ended plugs, as rings, or for work of large dimensions as spherical-end measuring rods.

Spherical-end Measuring Rods

These cylindrical rods (Figs. 8 and 9) are so lapped that their ends form sections of a true sphere, the diameter of which equals the length of the rod. A sleeve or grip of some insulating material is often fitted in

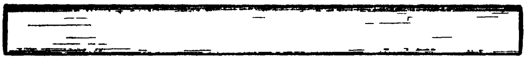


Fig. 8.—Spherical-end measuring rod

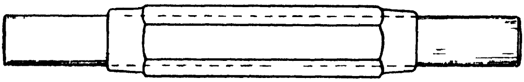


Fig. 9.—Spherical-end measuring rod with insulating handle

the centre to avoid the possibility of expansion due to handling, but this should be avoided because, in spite of insulating material, the heat from the hand will pass through to the gauge, and the length of time required for the gauge to settle to its original dimension would provide an opportunity for scrap work. It is far better to arrange that some external grip is clamped to the gauge, or that the gauge itself is held by rag or duster.

" Feel "

The difference between the " feel " when taken over a flat surface and then over a cylindrical piece with the gauge set in the same position necessitates that the standard used has the same contour as is required on the work at the position to be gauged. This difference will result, in the hands of most men, to a minus ·0001 in. on the work when gauging a flat section, if the gauge be set to a cylindrical standard.

Having studied the standard types of gauges, variations from these can be understood and designed when the need arises. This treatise would be too cumbersome if attempt was made to cover every possibility. It will be sufficient to describe only one much-used type, that of the depth gauge, for a counterbore or depth of slot which has to be accurate within a close tolerance. Fig. 10 shows an application of this type.

Receiver Gauges

The receiver gauge is used for the rapid viewing of numbers of parts and is largely employed when the inspection of components has to be done by unskilled labour or the time taken for inspection reduced.

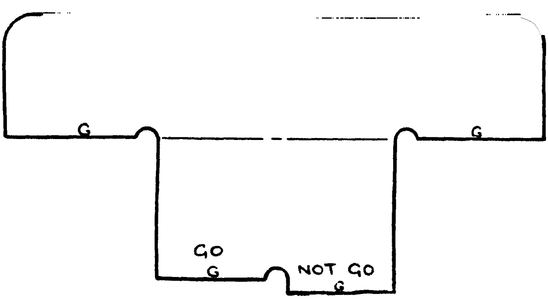


Fig. 10.—Depth gauge

On the component shown by the dot-and-dash lines on the illustration (Fig. 11) are four

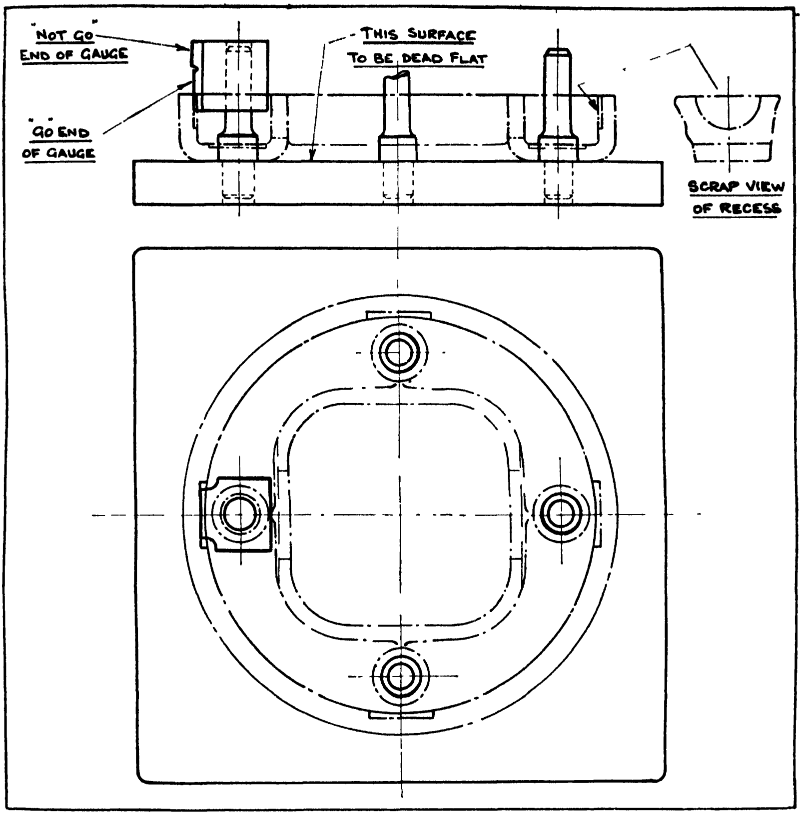


Fig. 11.—RECEIVER GAUGE

faces which have to be machined within the tolerance of + ·002 in. + ·000 in. from the centre line. Two of the components when assembled together form a complete cage for a coupling. The component is a pressing, the square hole not being machined. The four holes are therefore machined in accurate relationship and location from the centre square. It becomes necessary, therefore, to inspect the four thrust faces from these holes.

In order that any error occurring during the reaming of the holes is compensated as far as possible, the base of the receiver gauge is provided with four pins to locate in the holes, and in this instance these are ground to − ·0005 in. below the low limit of the holes. The component is dropped over these four pins and the gauge applied on each pin in turn,

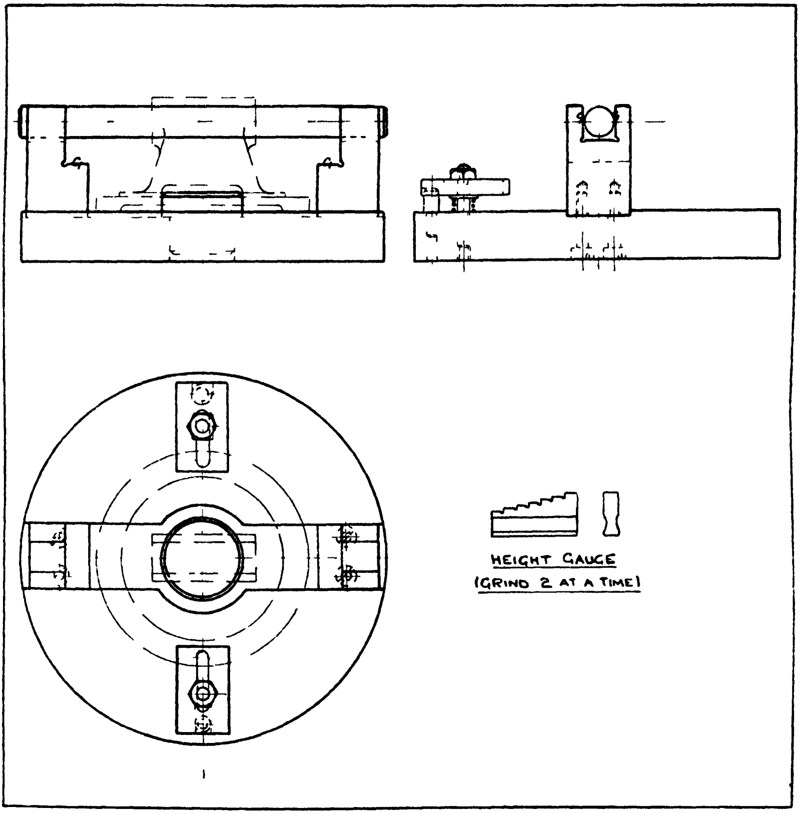


Fig. 12.—Receiver gauge

the difference between " Go " and " Not go " ends of the gauge being the tolerance, namely ·002 in. within which the components may be passed as correct.

A further type of receiver gauge is illustrated in Fig. 12. The long hole in the component shown must be square and central with a bore beneath it. The component is therefore dropped on a spigot ground to the low limit of this bore and a bar passed through the long hole. The component and bar will not assemble into the gauge unless the required accuracy is there. It is also essential that the long hole is parallel with the joint face. The centre distance between the joint face and the long hole is not important and the stepped-height gauge shown—the steps on which increase in one-thousandths of an inch—is provided so that in

the event of the centres varying, the variation from parallel may still be measured, and is determined by the amount the gauge passes under the bar, when applied on the step provided for this purpose.

A clamp is provided on either side, to prevent the component being lifted whilst applying the stepped gauge.

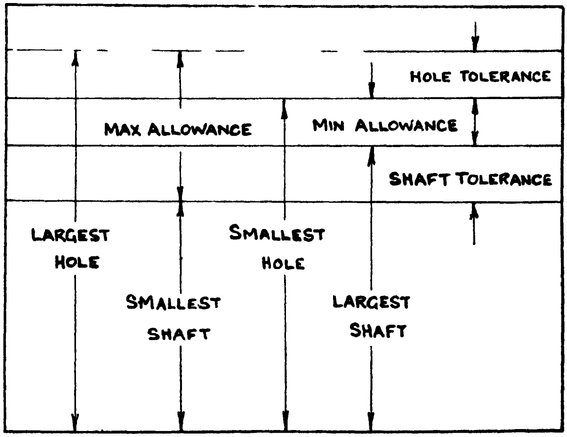


Fig. 13.—Relative positions of hole and shaft tolerances

Gauge Wear and Gauge-maker's Tolerance

All gauges, although hardened and lapped to a fine finish, are subject to wear, and consequently, because it is the "Go" end of the gauge which always wears, the tendency is to produce smaller holes and larger shafts than are required. New gauges also are not correct and can only be made within certain tolerances. Because the maximum and minimum dimensions of a piece of work must be adhered to—otherwise the amount was wrongly set originally—some part of the tolerance must be absorbed by the amount required by the gauge-maker (Figs. 13 and 14). This, wherever possible, should be kept within 10 per cent. of the total tolerance on the work. Because of the two contingencies given above, where it is required that stringent control is kept on the work, two distinct gauges are used, known as:

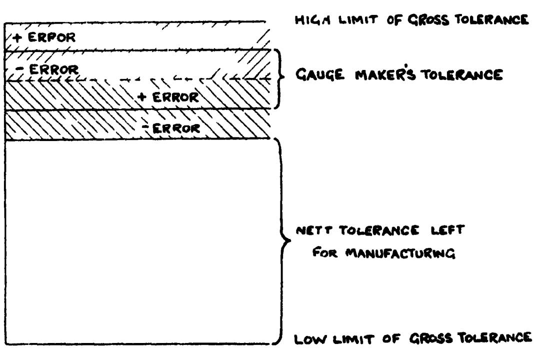


Fig. 14.—Gauge-maker's tolerance

"Workshop" and "Inspection" Gauges

The workshop gauge (Fig. 15) must encroach on the work

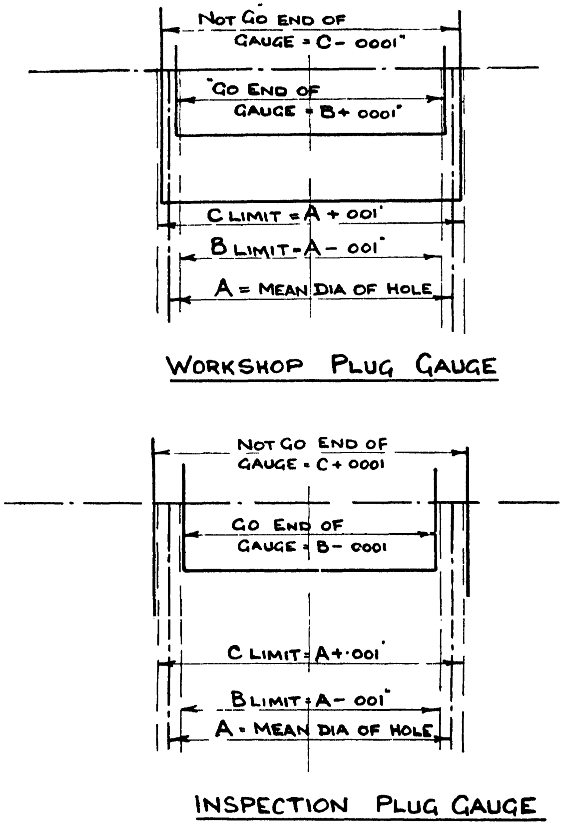


Fig. 15.—WORKSHOP AND INSPECTION GAUGES

tolerance by an amount represented by—

1. Gauge-maker's tolerance, and
2. Allowance for wear of gauges.

For example—in the case of a plug gauge, the "Go" end would be made plus the amount necessary, whereas the "Not go" end would be minus, but because the "Not go" end never enters the hole except in the case of wrongly made work, no allowance need be made for wear.

The inspection gauge must pass all work within the desired limits and must therefore be minus on the "Go" end and plus on the "Not go."

The difference from the workshop gauge can be determined from Fig. 15, from which it will be seen that the difference between the "Go" and "Not go" ends is smaller on the workshop gauge than on the inspection gauge. It cannot be expected that a machine operator will handle a gauge as delicately as a viewer, and also because, in order to remain on the safe side, he endeavours to work "tight" to the "Go" end of his gauge, any slight deviation on his part may still pass the inspection gauge which has the larger tolerance.

Allowance for Wear

This allowance (Fig. 16) must be kept as small as possible because, although the larger it is the longer can the gauge wear without producing scrap work, until the gauge has worn considerably, work will be pro-

duced to a smaller tolerance than necessary for correct functioning. The cost of producing such pieces will almost certainly be higher because of the replacement and resetting of the sizing tools. When the work tolerance is large, such as ·003 in., it would be safe to assume ·00025 in. for wear, but for smaller tolerances ·0001 in. must suffice.

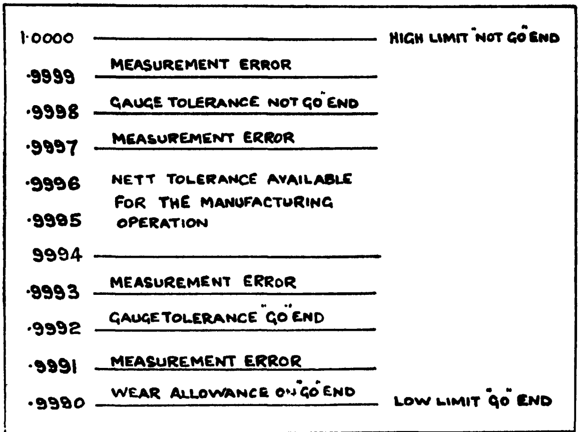


Fig. 16.—Allowance for wear

It is generally true that the harder the gauging surface the longer will it be before wear is apparent, or alternatively less need be filched from the work tolerance for gauge wear. To obtain this extra wear, many gauges are plated with hard chromium and from two to four times the " life " is obtained by this arrangement over the usual carbon-steel gauge, hardened and lapped. It has been estimated that standard slip gauges wear approximately ·00001 in. for every 1,000 times they are wrung together.

Accuracy of Gauges

For national standard or laboratory work, flat-ended length standards can be produced to an accuracy of one part in one million. Such meticulous accuracy is fortunately not required for everyday production. Reference bars and standard-end measuring blocks or slip gauges can be made to 2½-millionths of an inch per inch of length, although such bars and gauges when purchased for general shop use can be obtained to within 5-millionths of an inch per inch of length at a smaller cost. Cylindrical gauges up to 1 in. diameter can be made to within ± ·000025 in., but this is also not generally required, the best general accuracy being around ± ·00005 in. for a lapped gauge. Larger sizes will be proportionately inaccurate.

Snap gauges—the fixed type of external-limit gauge—because of the " whip " inherent in their structure cannot be made closer than ± ·0001 in.

Gauges for taper holes and shafts are not likely to be produced nearer than ± ·0001 in. at any diameter along the length.

Position or " receiver " gauges where there are perhaps several points

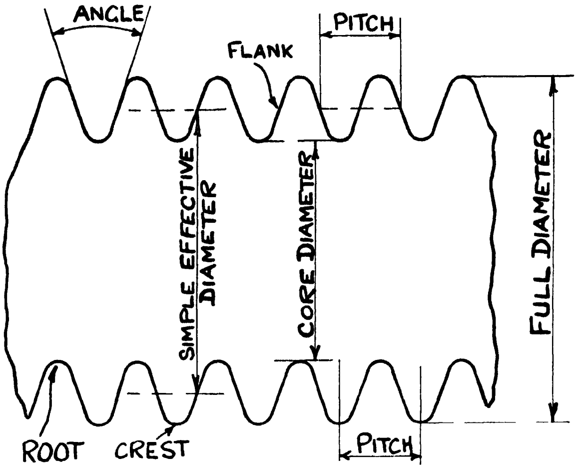


Fig. 17.—Screw-thread terms

of location and more than one position on the work to be controlled are not likely to be more accurate than within ± ·001 in. of the required dimensions. Any greater accuracy, if required, would involve considerable cost.

The foregoing is intended to convey and describe the fundamental principles of gauging which are positive enough for most purposes. When greater accuracy is required, it is the practice to transfer size from standard-end measuring blocks or slip gauges to the work by means of special instruments for comparison, designated comparators, many patented arrangements of which are available. It is not the intention of this work, however, to describe these instruments, illustrations of which are available in the technical press.

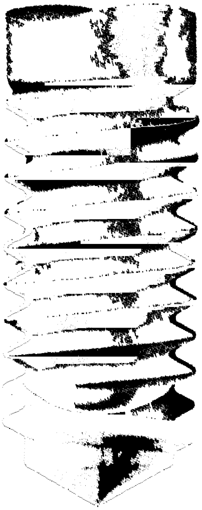
The question may well be asked, " What is the need for such high accuracy as that mentioned in the foregoing paragraphs ? " It will be appreciated that in the transference of sizes from the National Physical Laboratory down through the maker of end measuring blocks to the tool-room manufacturing inspection and workshop gauges, some loss of accuracy is entailed on each occasion, not only because of the fallibility of human endeavour, but because accuracy and cost must bear some relationship ; each step, therefore, takes advantage of the widest permissible variation. It will be realised, in consequence, why master gauges require to be as accurate as science and skill can make them.

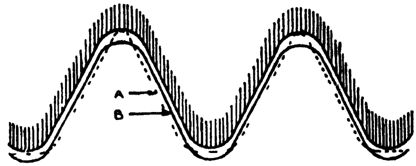
Screw-thread Gauging

Fig. 17 denotes the terms employed in the gauging of screw threads and are required in order that the following paragraphs can be understood by the student.

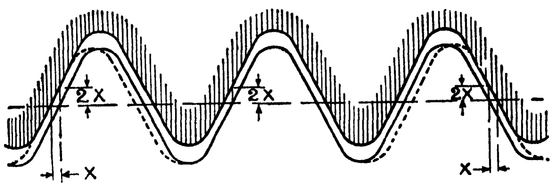
Simple Effective Diameter.—The length of a line drawn at right angles to and through the axis of the screw, measured between the points where the line cuts the flanks of the thread.

Compound Effective Diameter.—The effective diameter over a specified





Showing that a screw B can be a loose fit in a ring gauge and still be mechanically stronger than screw A, which is a tight fit.



Showing that the effective diameter of a screw is increased by approximately twice the amount of the pitch error.

(*left*) Showing that pitch error causes the end threads only to make flank contact.

Fig. 18.—Fit of screw threads. (*By courtesy of Alfred Herbert, Ltd.*)

length of thread and greater than the simple effective diameter by an amount due to the error in pitch. It can be measured only by a full-form gauge.

Full Diameter.—Twice the maximum radius of the screw or nut measured at right angles to the axis.

Core Diameter.—Twice the minimum radius of the screw or nut measured at right angles to the axis.

Flank of Thread.—The flank of the thread is the straight part of the thread connecting the crest and root.

The conditions governing plain hole and shaft work do not apply to threaded parts, whereas in the former instance certain kinds of fits are required ; in the latter case mechanical strength is the objective.

The strength of screwed parts depends not so much on the fit between the mating parts as the accuracy of the flank angle, and the corresponding area in contact and the correctness of the simple effective diameter. A screw which is a loose fit in its mating part may be stronger than a tightly fitting one, if its elements conform more closely to correct standards. It is possible that the tight-fitting screw is binding on its full or outside diameter, whilst it may be thin across the threads with a correspondingly small effective diameter and loss of strength (see Fig. 18).

The full and core diameter are relatively unimportant except that it is essential that they are not too large.

Apart from the first principle method of measuring screws by means of rollers and vee pieces, there are three distinct types of gauges in general use :

1. The screwed plug and ring gauge.
2. The Wickman adjustable thread caliper gauge.
3. The roller adjustable thread caliper gauge.

A single full-form plug or ring-screw gauge is not adequate to control all the elements, and if the screwed-gauge system is used, further gauges are required with certain thread elements eliminated. One set will check the effective diameter, others the full diameter and radius, and another the core diameter.

When the quantities of screws and nuts to be produced are relatively small, however, it is usual to adopt full-form screw and ring gauges and rely on the accuracy of the cutting tools in the form of taps and dies.

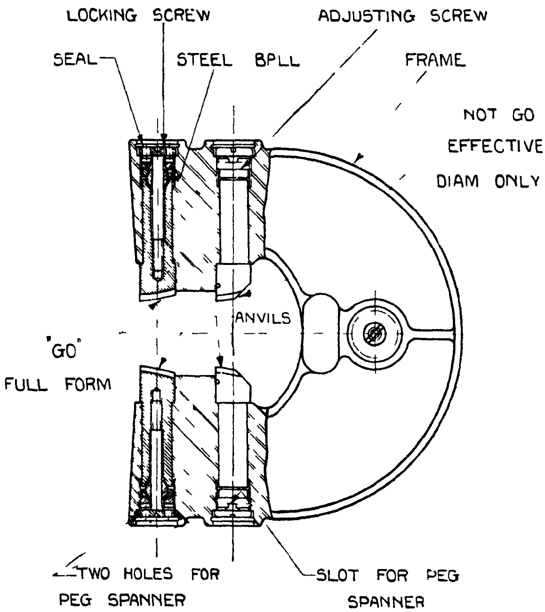


Fig. 19.—The Wickman screw gauge

Showing the construction of the anvils of the Wickman Patent Adjustable Caliper Gauge. (*By courtesy of Alfred Herbert Ltd.*)

Because of the number of elements to be controlled, screw gauges cannot be made so accurately as the gauges previously described. Ordinary screw gauges can be made to either plus or minus ·0006 in. to $1\frac{1}{2}$ in. diameter.

The inspection rings being up to this amount plus, and workshop rings being down to this amount minus, inspection plugs will be so much minus and workshop plugs will be so much plus.

Master- or check-screw gauges are made to finer tolerances, but these are rarely required for commercial purposes.

The Wickman gauge has four anvils, which are adjustable, are complete forms of the thread, and no oversize element of the screw thread can

pass them. The width of the anvils forms a check over the pitch in the required length of screw engagement. The " Not go " pair of anvils at the rear are arranged to check effective diameter only, and are formed so that they are clear at both the crest and the root, and by gauging one thread only, pitch error cannot interfere with their accurate functioning. The part threads on these anvils are arranged at the ends, so that gauging increases the effective diameter of screws. A screw thread must therefore be small enough to compensate for pitch error if it is to pass the " Go " anvils. If the pitch error is too great, then to pass through the " Go " anvils the effective diameter must be made too small, with the result that the thread may pass the " Not go " anvils and come within the category of those to be rejected.

The threads on the anvils are annular and are form relieved so that they do not interfere with the helix angle of either right- or left-hand thread, for both of which the gauge can be used.

Wear is accommodated by grinding the faces of the anvils and re-setting to reference plugs.

The sharp edges of the anvils have an advantage, in that the gauge is not so easily sprung over the work as in the roller type of gauge, described in the succeeding paragraphs.

For large-diameter work, say 3½ in. and over, it is advisable to consider the roller type, which is capable of withstanding the quite severe treatment to be associated with greater weight. In principle this type is somewhat similar to that previously described, except that the gauging parts are completely circular.

Two separate types of roller thread gauges are in use. In construction the gauges are similar to the Wickman type, except that rollers are substituted in place of the vee'd anvils. The upper rollers float in an end-wise direction and consequently assume correct relative position with the threads to be gauged, and no " searching " of the correct position is necessary. On the type made in this country the rollers are threaded on the periphery, with the result that separate gauges are required for right- and left-hand threads of similar size.

On smaller sizes the rollers are made the same diameter as the work to avoid interference with the helix angle of the threads when gauging. On large sizes where it is impracticable to make this arrangement, the thread form on the roller is compensated to accommodate this possibility.

On another type of roller gauge, of Continental make, the rollers have annular grooves instead of threads. This permits the same gauge being used for right- and left-hand threads. The interference, in consequence, is small and can be discounted for most commercial purposes. On both roller types the distance between the rollers is adjustable, the front rollers being full form and the rear rollers clear at the full and root diameters.

Chapter IV

CUTTING-TOOL MATERIALS

BEFORE considering the design of small tools a brief survey of cutting-tool materials, giving an indication of the direction in which each may be most satisfactorily applied, is necessary. No hard-and-fast rules can be laid down ; many considerations have to be taken into account, such as :

The material to be cut.

The shape of the piece.

The means available for holding the work.

The rigidity of the machine tool available.

The economics of the quantities to be machined and the sum available for expenditure on tools.

Carbon Steel

Carbon tool steel or cast steel is now, apart from the wood-working trades, little used as a cutting medium except where cutting speeds are low or the tools will be used by hand. Being the cheapest among the cutting materials, where initial cost is an important consideration, taps, reamers, and broaches can be satisfactorily made from it, particularly if any of the alloying elements, such as tungsten or chromium, are added. As carbon steel softens permanently at temperatures above 225° C., the cutting speed must be regulated accordingly.

Jig, fixture, and press-tool parts requiring hardening can be made from this material, especially when time for manufacture is insufficient to allow for the carburising operation required for the cheaper case-hardening steels.

High-speed Steel

High-speed steel containing 14, 18, and 22 per cent. tungsten, with small inclusions of the other alloying metals, is used for almost all types of cutting tools, including the taps, reamers, and broaches mentioned above, and is the steel which has superseded the carbon tool steel because of the much faster speed at which it will cut satisfactorily ; softening of the tool does not occur at temperatures below 660° C. Care should be taken in the selection of high-speed steel for particular tools—for form tools a steel should be chosen which distorts as little as possible in hardening, so that the amount of stoning or grinding required for correcting is kept to a minimum.

Form tools, because of the length of cut, have often to withstand heavy load ; a steel, therefore, of too brittle or " short " a character is

to be avoided. It is false economy to use a poor-quality steel on what is an expensive tool to produce.

For plain turning tools, unless cuts are very heavy, cheaper steel may be used, the amount of distortion in hardening not being of importance; neither does "shortness" matter. All that is required is that the tool is hard enough to make frequent grinding unnecessary. On very tough materials, in order to make the tool more resistant to abrasion and raise the temperature at which the edge breaks down, the addition of cobalt is required often to the extent of 15 per cent.

Tungsten Carbide

In order that the properties and performance of these materials can be appreciated, it is necessary that some knowledge of their composition and manufacture is acquired. Methods of producing this material vary, but generally pure tungsten carbide is pulverised to a grain size of ·0001 in. This flour is then thoroughly mixed with a cemented matrix of metallic cobalt, the whole then being shaken through gauze sieves.

Specific quantities, in accordance with the shapes required, are then placed in dies, the punch member of which transmits heavy hydraulic pressure to the compound.

The material is now hard enough to be handled and removed from the die and subjected to a sintering process in a hydrogen atmosphere in carefully controlled electric furnaces. Following this process, the pieces are cut and ground to the required shape before the final sintering, which follows along the lines of the previous one, except that it is more prolonged. To prevent cracking, the cooling process is a slow one and is arranged in the furnace so that the pieces when exposed to the atmosphere coincide approximately to the room temperature. The hardness of the material is now little less than that of a diamond, and can only be formed by specially prepared grinding wheels.

Whilst this material is hard and strong in compression, its tensile strength in relation to high-speed steel is only about 50 per cent. It is not strong enough to take the loads likely to be imposed upon it, and is therefore used as tips to shanks of other and stronger material. It will, however, be apparent that it can be used with advantage on those materials which quickly break down the cutting edge of high-speed steel—such as cast iron, Bakelite, fibre, etc.

For the shanks, carbon steel, the carbon content of which should not be over 0·5 per cent., giving a tensile strength of around forty-five tons, has been found the most suitable. If a higher percentage of carbon was permitted, difficulty would be experienced when brazing the tip, as at a temperature necessary for this operation the shank would tend to temper, which condition would not be satisfactory for secure brazing. It is advisable also that the back and also the base of the tip are nicely fitted to the shank, as the success of this material depends on the support

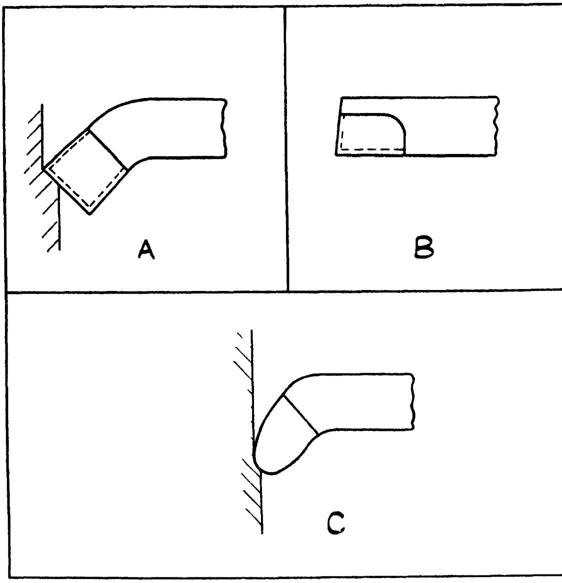


Fig. 1.—CEMENTED CARBIDE TOOLS

it obtains from the shank, coupled with the rigidity of the machine and work-holding devices. The shank sizes should always be as large as possible. Examples of good practice are shown in Fig. 1. Because of the physical properties of the material, effort should be made to reduce chip pressure to a minimum, and it is preferable, particularly on heavy cutting, for tools to be designed as A and B rather than as C, which should only be used for light turning and facing, when a better finish is required.

Tungsten carbide has, however, an affinity for steel, with the result that when cutting, particles of the steel build up and weld themselves on to the top of the tool just behind the cutting edge, so that when the particles break away, pieces of the tungsten carbide are carried with them, causing the tool in time to break down completely or to require regrinding. It is, therefore, not entirely satisfactory for machining steels.

Tantalum Tungsten Carbide

The addition of tantalum to tungsten carbide has resulted in a material less prone to the " building up " experienced with tungsten carbide when machining steel. It has, however, one disadvantage, in that because of its lower affinity for steel, greater difficulty is experienced in brazing the tips on to the shanks, and great rigidity is required in machine fixtures and tool-holders for its successful application ; nevertheless, given the right conditions, it can be used successfully on steel.

Molybdenum-titanium Carbon Alloy

This, one of the latest of the cemented carbides to be offered as a cutting tool material, is manufactured in much the same way as the

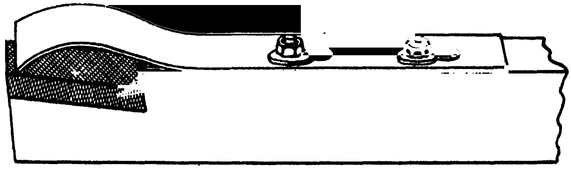


Fig. 2.—SPRING STEEL CHIP BREAKER

tungsten carbides, but carbides of molybdenum and titanium are employed instead of tungsten. It is claimed that it can be used successfully for cutting all forms of material, including non-ferrous metals and non-metallic substances as well as cast iron and steel. It is capable of producing a much better finish on the work than the other carbides, but its application appears to be limited to light cuts at very high speed, and certainly shows up to advantage for this class of work, particularly on high-tensile steels, where its resistance to abrasion or wear is remarkable, the same superiority not being apparent on softer steels. The same difficulty with brazing occurs as is the case with the tantalum carbide; also great care has to be taken when grinding, if cracking is to be avoided.

Because of the speed with which the chip leaves the cutting edge of the tool, there is a likelihood of it being dangerous to the operator, or particularly troublesome if it does not break, but comes away in a continuous ribbon. When this occurs it is advisable to fit a chip breaker, an example of which is shown in Fig. 2. The top leaf is made from spring steel and hardened, and the chip, after leaving the cutting edge, is guided into a short spiral which will quickly break into short lengths. It is possible in some cases, where there is sufficient tip available, to slightly lip the cutting edge to effect this result, but it is not to be generally recommended on these expensive materials.

Cobalt-chromium-tungsten Alloy

This material is the oldest among this range and is a cast substance. Its ability to resist abrasion is greater than high-speed steel and it can be used at higher speeds. Its tensile strength being greater than the tungsten carbides, it can be used in certain cases without the backing provided by the tool shank. It has not, however, the tensile strength of high-speed steel, and for normal machining operations it is best used in the tipped form.

This material occupies an intermediate position between high-speed steel and the cemented carbides, and is less costly than the latter. It can be used to advantage on cast iron and non-ferrous metals, but it is not so successful when machining high-tensile steels. A favourite and successful application is for inserted blade-milling cutters for machining cast iron in particular, the blades being solid pieces.

CERAMIC CUTTING TOOLS

It is difficult to visualise the use of ceramics for cutting metals. Nevertheless, ceramic tools are used with considerable success for machining practically all metals, including the "difficult" titanium and vanadium. This cutting material was first developed around the nineteen-thirties for machining abrasive materials such as carbon, graphite, plastics, fibre, asbestos, etc., which are difficult to machine with ordinary metal-turning tools. However, by slightly altering the composition and manufacturing methods a vastly improved material has now been obtained.

Hardness

One such ceramic has a hardness approaching that of diamond and comprises 95 per cent pure aluminium oxide plus silica and certain refractory oxides: no binding medium is used, the ingredients being formed

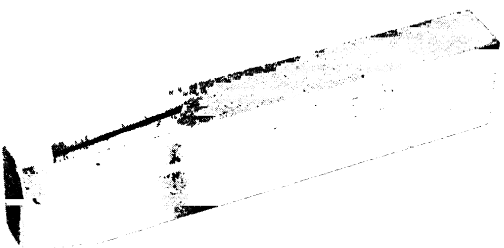


Fig. 3.—"SINIOX" SQUARE TOOL HOLDER AND DIAMOND SHAPED CERAMIC INSERT *(English Steel Corporation Ltd.)*

into a homogenous mass by sintering at high temperature. Although it is brittle enough to be shattered with a hammer, it has the remarkably high-compressive strength of 100 tons/sq. in. It is not affected by vibration in the same manner as other ceramics, as may be seen from the fact that the tools can be used on machines that are not bolted to the floor.

The Cutting Tips

The tools are made in the form of moulded tips or inserts which are clamped to tool holders: the arrangement is generally such that a negative cutting rake is provided. The inserts supplied by one firm are available in three shapes: (1) round—for heavy-duty turning and facing; (2) square —for general turning and facing work; (3) diamond—for turning and facing square shoulders, etc (Fig. 3). Each shape can be supplied either plain or with moulded-in chip breaker. All the edges can be used before the insert is discarded: the square type provides eight cutting edges, and the round inserts can be rotated to innumerable new positions. In addition to the above type of tool, fixed-tip types are also being developed: with these, the ceramic insert is hard-soldered to a steel shank.

Special Features

Difficulties associated with "build up" do not occur when using this cutting medium because its non-metallic and chemically unreactive nature precludes the possibility of workpiece material welding on to the tool. Additional factors which assist in attaining maximum cutting efficiency are the exceedingly low-coefficient of friction of the ceramic in comparison with conventional tool materials, and the extreme hardness which is maintained at all times irrespective of temperature variances at the seat of cutting. Thermal conductivity is half that of tungsten carbide, which means that the heat generated during cutting is repelled by the tool tip, where it normally causes wear, and is used as a softening agent on the swarf. It will be realised that immediately the swarf becomes plastic it serves as a secondary cutting medium, thus assisting the cutting action.

In addition to the advantage of long life between regrinds, these tools produce an excellent finish on the workpiece, and they are also eminently suitable for fine finish-turning of brass bearings and magnesium alloys.

Ceramic-tipped milling cutters have been produced for machining graphite; and tests show them to be capable of giving a life between grinds at least 2½ times that of tungsten-carbide or high-speed steel.

Speeds and Feeds

Because of the great variety of materials used in the engineering industry, it is, of course, necessary to adjust machining conditions to suit the type of material to be cut, but the general details given below serve as a guide to the workshop use of these tools.

The peripheral turning and boring speeds should be as high as possible consistent with satisfactory operation of the machine. Due to inherent properties of the material, speed does not have any detrimental effect upon the tool, and it can be at least twice that employed with tungsten-carbide tools. The excellent abrasion-resistance properties enable the tools to be used with a relatively large radius, allowing a higher feed per revolution of the workpiece for a given degree of surface finish.

The depth of cut can be as great as possible, consistent with satisfactory swarf removal; it is also possible, however, to employ very small depths for fine finishing. It is preferable to use these tools without any cutting fluid, but if a liquid is found to be essential a copius flood should be directed to the seat of cutting.

As a rule, cutting angles that control swarf formation, i.e., the rake angles, should be slightly less than those employed for tool materials in general use. Clearance angles of about 6° are suitable for machining plastics, with a secondary clearance of about 8°.

Ceramic tools are capable of machining hardened-steel bars at speeds of 2,000 surface ft/min., and feeds as high as ·05-in. per revolution. It is claimed that the tool life is several times greater than that of carbide tips. Only one grade is made, but this is suitable for all metals, including

TYPICAL LATHE-TURNING SPEEDS FOR CERAMIC TOOLS

Material	*Roughing (ft/min.)*	*Finishing (ft/min.)*
Up to ·2 carbon steel	400—800	1,000—1,300
·2—·3 carbon steel	300—600	800—1,000
·3—·4 carbon steel	250—500	700—900
·4—·6 carbon steel	200—300	400—600
Close-grained cast iron Brinell hardness 217	500—1,000	1,000—1,500
Commercial brass	Unlimited, dependent on motor speed and power available	
Aluminium	Unlimited, dependent on motor speed and power available	

titanium. Under actual production conditions, EN 24 alloy steel (50–60 tons tensile strength) has been machined at 1,580 ft/min., with a feed of ·012-in. per revolution and depth of cut of ·080-in.: the quality of surface finish was excellent, and after 30 minutes of cutting the tool wear was only ·006 in.

After making allowance for all factors, it is estimated that the cost of these tools is about one-third that of cemented carbides. In fact, after all edges have been used it is cheaper to discard the ceramic tip than to regrind it. As a matter of interest it may be mentioned that ceramics are also successfully used for milling cutters, boring bars, drills and superfinishing tools for machining steels.

Tool Grinding

Conventional wheels are unsuitable for grinding ceramic tools, and the makers therefore recommend the use of diamond wheels on a machine free from vibration; the tool should be flooded with a copious supply of cutting oil. When grinding ceramics, in comparison with carbide tools the material can be removed at a much higher speed, although a similar technique is employed. Bakelite-bonded diamond wheels of 200–400 grit are suitable for finish grinding, and coarser wheels up to 200 grit can be used for removing stock.

The best results are obtained with diamond wheels, but if they are not available it is possible to use the green grit (silicon carbide) type. It should be noted that because the rate of stock removal is considerably lower when grinding with silicon-carbide wheels instead of diamond, it is essential to use only light pressure, thereby retarding the development of excessive heat; if this is not done, the tip may be cracked and broken.

Chapter V

SMALL TOOLS

SMALL tools are probably the most neglected part of many tooling programmes, and yet they may be even more important than the actual jigs and fixtures. It is relatively easy to produce the first few of any type of component without jigs or fixtures, since the parts may be machined with temporary equipment and holes can be marked off for drilling. It may, however, be almost impossible to produce the same component without some special tap or formed cutter.

It frequently happens in tooling programmes that all the jigs and fixtures are designed firstly, and the small tools receive secondary consideration. Tool manufacturers will on occasion quote longer delivery periods for the small tools required than for the jigs and fixtures, causing delay in the production programme.

Cutting tools cover a wide range, but the fundamentals of correct design do not vary in proportion. By adapting the principles in the following examples to tooling requirements, the designer is unlikely to make any serious error.

DRILLS

Although drills (Fig. 1) are now standardised and specialised, it is highly essential that the jig-and-tool man should carefully study the correct design of this tool, because not only will he, on occasion, be called upon to specify on his tool layout the type of drill required to suit the material being handled, but he may also have to design into a combination tool a part which will perform all the functions of an ordinary drill.

It is important that the cutting edges are ground at the correct angle to the axis of the drill ; an angle of 59° has been found most suitable for general purposes. Also, both cutting edges must be of equal length. *A* shows a drill correctly ground ; at *B* and *C* it can be seen how impossible it is to obtain accurate results with inaccurately ground drills. At *B* the drill has cutting edges of equal angle, but different length. The point of the drill is consequently out of centre and an oversize hole will result. At *C* the cutting edges are not the same angle, and although the point is central, all the work falls on one lip.

The correct clearance angle on the periphery is 12°, as indicated at *D*, and the centre angle, which will be found to give best results combined with the 12°-clearance angle, is 130°, as shown at *E*. One of the main

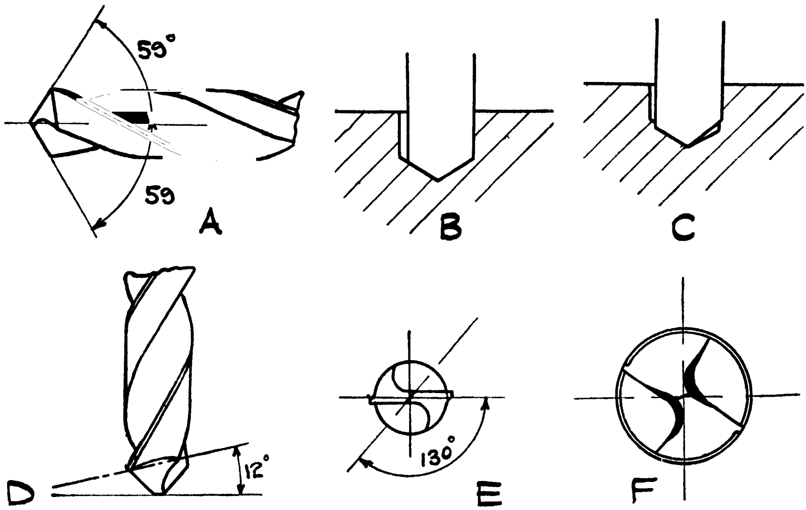


Fig. 1.—Drill grinding

causes of drills splitting up the web, particularly when heavily loaded, is insufficient lip clearance.

Where heavy feeds are required on soft material, improved results can be obtained by increasing both lip-clearance angle and the centre angle 1° or 2°.

Web Thickness, Fluting, etc.

A twist drill is made slightly tapered on its outside diameter throughout its length at the rate of ·0005 in. to ·001 in. per inch of length in proportion to the diameter, the larger diameter being at the cutting end. The thickness of the web is also increased towards the shank or chucking end at the rate of ·012 in. per inch for drills under ½ in. and ·010 in. over 1 in., with the result that as the drill becomes shorter by grinding, it is necessary to thin the web. This should be done equally in each groove, (see *F*), so that the point is brought to its original thickness.

For ordinary good purposes, the helical fluting on drills is usually from six and a half to seven times the diameter. Some makers provide an increasing lead which at the point is six times and after one turn of the helix seven times the drill diameter, but when used on soft materials, particularly Elektron metal, the spiral lead must be considerably increased, otherwise it will be found that the chips bind up and, by clogging the flukes, cause drill breakage.

Helical fluting of 10° will be found satisfactory, and a centre angle of 130° with a clearance of 15°.

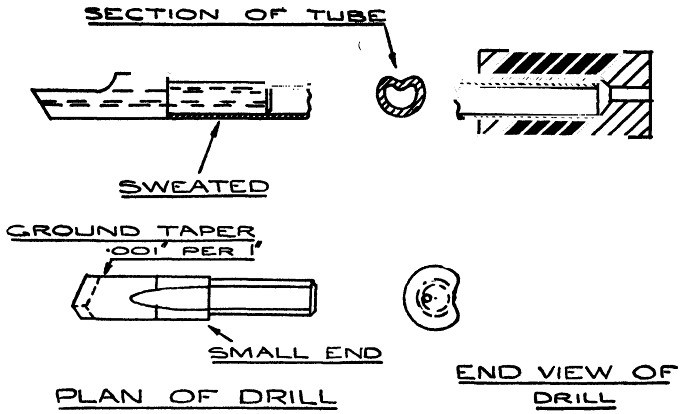


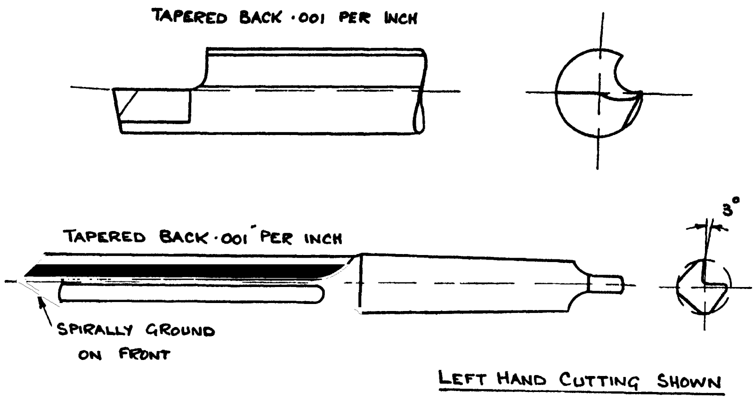
Fig. 2.—RIFLE DRILL

Rifle Drills

Fig. 2 shows a type of drill used for long holes, where accuracy of alignment is essential. The body of the drill is made from kidney-shaped tubing on to which a high-speed steel bit is soldered. The high-speed bit is ground at the end, leaving only half a diameter, and is reduced in diameter along part of its length, which part is inserted into the tubing. The groove in the tubing allows space for the swarf to escape. The lubrication pressure must be high enough to eject the drillings rapidly enough to prevent binding. A pressure of 800 lb. is usually sufficient.

The adaptor on the opposite end is made of a convenient size to suit the chuck or holder, and pressure-fed lubrication to the end of the drill is obtained by drilling the hole through the bit in a position to meet the hole in the tube. The hole in the work should be started to the correct size and true before inserting the rifle drill. On the $\frac{3}{16}$-in. diameter drill shown the speed of 1,000 r.p.m. and a feed of ·0005 in. were used satisfactorily, the depth of hole drilled in this instance being 15 in.

The high-speed steel-cutting portion is ground to the diameter of the hole required and the tubing remains slightly below this diameter for clearance. The length of the bit on the $\frac{3}{16}$-in. size is 1 in. Larger sizes should be made to a reasonable proportion so that the bit is long enough to act as a pilot to cut the hole true and in line. The bit is ground slightly taper, about ·001 in. per inch being generally satisfactory, the larger diameter being at the cutting end. This is done to obviate any tendency to bind should the cutting edge become dull. When using this tool, the work is revolved, the drill remaining stationary except for being fed into the work.



Figs. 3 *and* 4.—" D " BITS

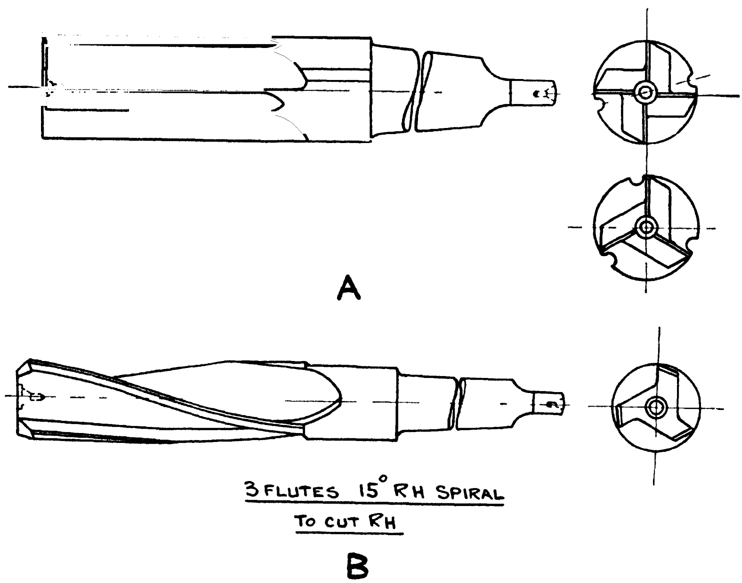


Fig. 5.—CORE DRILLS

" D " Bits

Fig. 3 shows a similar tool, except that in this instance it is used for truing up a long hole to size, after it has been previously rough-

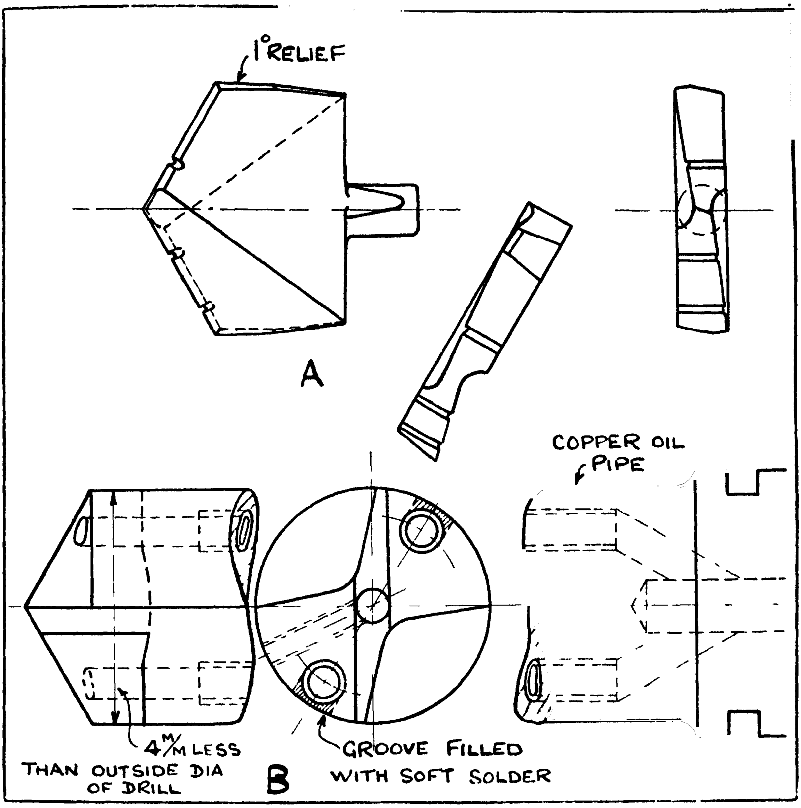


Fig 6.— SPADE DRILL

drilled or bored. This type of tool is generally used for larger diameter work. The cutting bit in this instance is fluted, not being ground to half-section as was the case with the rifle drill, so leaving a greater portion of the diameter to act as a guide and pilot.

An alternative " D " bit design is shown in Fig. 4. This type has proved more successful in truing up long holes in cast iron in order to bring them into alignment after roughly drilling the hole. The cutting edge on the front of the " D " bit is ground after the manner of the ordinary twist drill, except that only one cutting edge is provided. To reduce friction the outside diameter is relieved by milling flats longitudinally, so leaving three piloting portions.

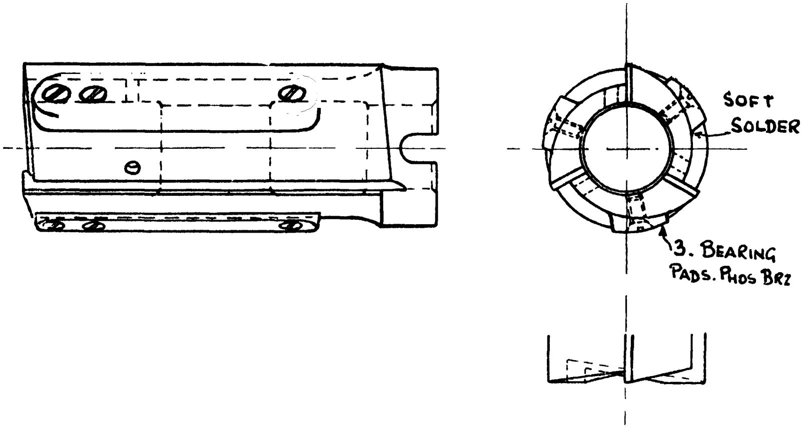


Fig. 7.—CORE DRILL FOR FINISHING LONG BORE

Core Drills

Fig. 5 shows three examples of core drills. These are used for the opening up of rough holes, either as cast, or pierced, as in the case of stampings. When accuracy is required, core drills are made $\frac{1}{64}$ in. undersize for a subsequent reaming operation. It is necessary that they are piloted through drill bushes, and for this purpose the outside diameters are ground circular and a substantial " land " is left on that part of the outside diameter remaining after the flutes are milled. On a 2-in. drill approximately $\frac{1}{8}$ in. should be allowed for " land." The tools, being front cutting, are reground on the front edges only. Examples shown at *A* are suitable for cast-iron pieces ; the spirally fluted type at *B* is more suitable for steel. This type has also been found more satisfactory on Elektron metal than the straight fluted type.

Spade Drills

On long holes over 1 in. in diameter where accuracy of alignment is not an essential feature, faster production can be obtained with the type of drill shown in Fig. 6, which will stand much heavier feeds than the rifle-type drill, and further reduction in time can be effected because the hole need not be accurately started, as is necessary with the two drills previously described. The work only needs to be centred before drilling is begun.

The bit of this drill *A* is supported in a slot milled in the end of the drill body *B*, and is prevented from falling out by a grub-screw which clamps on to the small circular portion integral with the bit. The cutting edges are nicked to break up the chips. Two grooves are provided throughout the length of the drill body down which the chips pass. The chips are washed back along these grooves by pressure-fed lubrica-

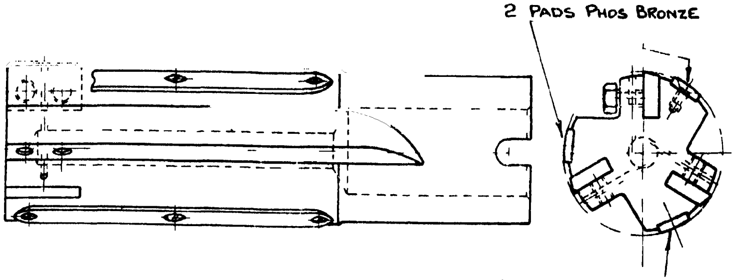


Fig. 8.—ALTERNATIVE CONSTRUCTION FOR CORE DRILL

tion, which passes to the drill point via two copper tubes laid in slots cut for their reception along the body. After the tubes are positioned the remainder of the slots are filled with solder to keep out swarf.

As with the rifle drill, this type is usually used in the horizontal position and does not revolve. The slots cut in the shank end are to prevent the drill rotating under the cut. A hole 5 ft. long and 2½ in. diameter is not likely to be produced with these drills closer to true alignment than ·10 in., and the finish is likely to be rough.

Core Drills for finishing Bores

Should the work necessitate better finish and alignment, then the hole may be drilled smaller and a core drill which is shown in Fig. 7 fixed to the end of a body of suitable length may be fed through. This tool has three cutting edges and is piloted in a true path by means of three brass pads, let into the drill, screwed and finally soldered into position An alternative method of designing this tool is shown in Fig. 8.

In this type three inserted blades are clamped in the drill body, and of the three pads one is made from lignum vitæ, this one being left ·010 in. larger in diameter than the blades are to cut. This is done so that when the lignum vitæ enters the hole behind the cutting blades, it is scraped to size by the end of the hole, thereby holding the brass pads closely against the inner wall.

Lubrication is carried to the cutting edges through the centre of the drill and by way of small holes drilled from the outside diameter into the centre hole. So that this tool, as well as the previous solid type, suffers no bias when starting, the hole required should be bored to size with a single-point tool for a short distance along its length before the core drill is inserted.

Stepped Reamer for Fine Finish

If a finer finish than can be obtained with this three-lipped cutting tool is required, then a reamer as shown in Fig. 9 can be passed through

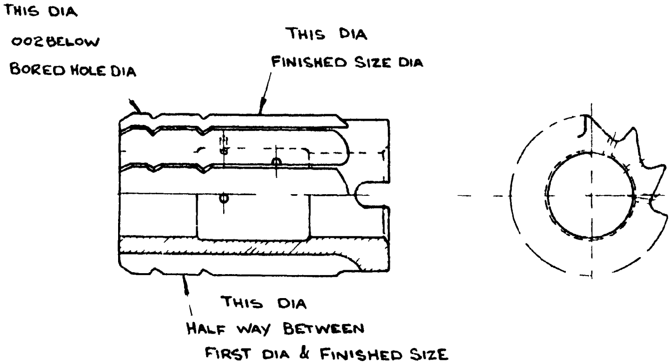


Fig. 9.—STEPPED REAMER

the hole and arrangements made that the previous tool is approximately ·016 in. to ·020 in. undersize and three steps on the reamer arranged so that the first step is ·002 in. below the hole previously bored, and the centre step is half-way between the first and the last one, which is the finished size required. Lubrication is again arranged by small holes drilled from the outside into the centre bore of the reamer.

REAMERS

Reamers, like twist drills, are now highly specialised and are the tools most generally used for the sizing and finishing of holes. The jig-and-tool designer will be called upon to draught many special requirements of the reamer type, and it is therefore necessary that he is acquainted with the correct design of this important tool.

Fig. 10 shows an ordinary standard general-purpose reamer, the fluting on which is made left-hand spiral to prevent the tool from feeding itself into the work, as would be the tendency if the spiral was made right hand. The flutes should be so made that the cutting edges have a slight negative rake, and further, to prevent chatter through too even balancing of the cut, the fluting should be unevenly spaced.

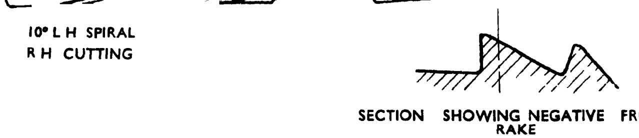


Fig. 10.—STANDARD REAMER

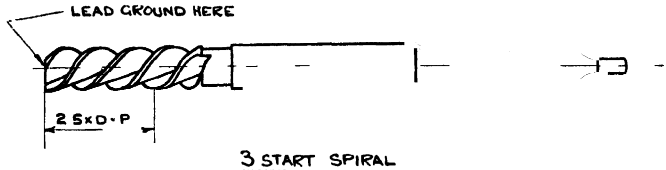


Fig. 11.—Reamer for free cutting work

A small amount is quite sufficient—a variation of 2° or 3° in spacing being adequate.

A slight " land " that is part of the true diameter should be left to act as guide and pilot for keeping the hole in line. This can vary from ·010 in. to ·032 in. in proportion to the diameter of the reamer.

Variations from this recognised general-standard type will be required for certain materials. On very free cutting materials, such as Elektron metal, a reamer as shown in Fig. 11 is necessary for satisfactory results. The lead of the helical flute should be in this case 2·5 times the diameter.

Fig. 12 shows a very much used type of reamer which is not so standardised, except for small taper pin work, and is for finishing taper holes. In laying out reamers for this work the jig-and-tool man must be quite sure, not only that the smallest end of the reamer will go through the hole being reamed, but also that the larger end is big enough in diameter, thereby making the reamer long enough to stand a number of regrinds, so prolonging its life.

Having determined these two diameters, i.e. both the small and the large end, a cross-section of these two positions should be laid out on the board with a view to obtaining adequate chip clearance and tooth strength, and from these two sketches the angle at the bottom of the fluting can be determined. Various adaptations of the reamer are used, such as the expanding type, which can be adjusted for wear, of which there are numerous examples, and the shell type of reamer, which is fitted on to the end of arbors in order to extend the tool for long holes.

Two-fluted Reamer

When the position of the hole to be reamed permits the tool to be passed through and, at the same time, a very fine finish is required,

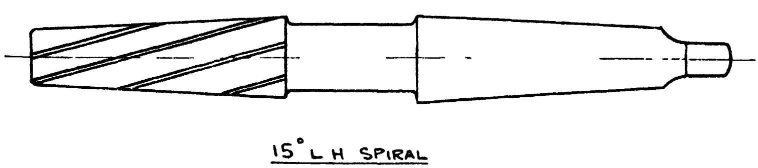
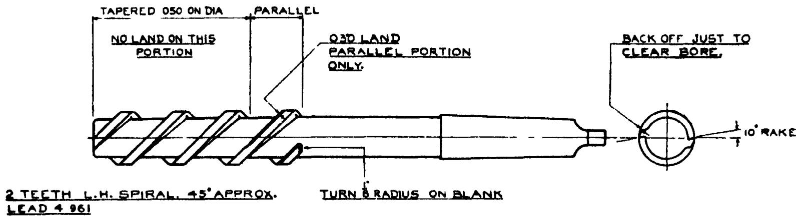


Fig. 12.—Taper reamer



SPECIAL SPIRAL REAMER

Fig. 13.—SPIRAL REAMER FOR FINE FINISH

the reamer shown in Fig. 13 will give really excellent results. It is probably a little more costly to manufacture and more expensive to regrind. The additional cost, however, is well worth while because a fine finish is obtained with much greater certainty than with the standard parallel type of reamer as previously described.

Two flutes only, which allow plenty of room for swarf clearance, are necessary. The helical angle of the fluting is 45° and left-hand, and a front cutting rake of 10° will be found adequate on all classes of steel, including malleable castings.

The principle of the reamer is that the cutting is done along a considerable length of the diameter, instead of on a chamfer on the front of the reamer. For instance, on a 1½-in. diameter reamer, if the reaming portion is made approximately 5½ in. long, the last 1½ in. only is made parallel and to the top limit of the hole required. The other 4 in. gradually tapers towards the front to a dimension just below the size of the previously drilled hole. If a drill $\frac{1}{32}$ in. undersize makes the original hole, the front part of the reamer can be made ·005 in. to ·008 in. below this dimension, the diameter being approximately 1·460 in. to 1·463 in. The reamer should run at approximately twenty revolutions per minute and a fast feed employed.

On the first 4 in. of the reamer—i.e. the tapering portion—the two flutes are ground to a sharp cutting edge without " land." On the last 1½ in., however, a " land " of approximately $\frac{1}{32}$ in. is provided in order to ensure that this diameter maintains size as long as possible. When regrinding the reamer, the tapered portion is ground, so making the smallest diameter still smaller and reducing the length of the parallel portion. The sizing qualities of the reamer are therefore available until the parallel portion is completely ground away by the resharpening.

Reamers for tapered holes made in like manner will give equally good results. A difference in manufacture is, however, necessary in so far that the smallest possible amount of " land "—even if only a few thousandths of an inch—should be employed. When regrinding, the reamer will be

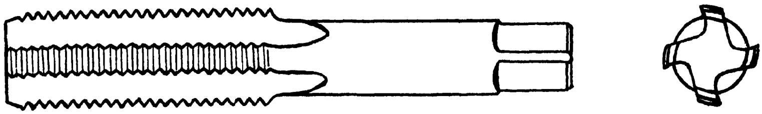


Fig. 14.—STANDARD HAND TAP

rotary ground and then backed off again to reduce the "land" to a minimum. If too great a "land" is used, the pressure required to make the reamer cut will be excessive.

TAPS

Another highly standardised tool is the tap for threaded holes. Although there are so many elements in the screw thread to control, very accurate results can be obtained with ground-thread taps. It will be found from experience that various metals will require slight alteration in tap design. The tap most generally in use is as shown in Fig. 14, and is supplied with eccentric relief, a portion of its diameter only being left circular. This relief is slight, being as a general rule less than ·001 in. in the width of one threaded portion between the flutes on taps up to $\frac{5}{8}$ in. diameter. This relief prevents the tap from binding and breaking.

Whilst this type of tap will be satisfactory when it is possible to pass the tap completely through the hole, and the angle in the flute on the back of the threaded portion provides considerable strength, it would be likely to cause chips to wedge on reversing to extract the tap. It is therefore better to standardise on a tap, the fluted portion of which is circular, or at least radial at the back of the teeth, as in Fig. 15. The circular groove provides rake on the cutting edge and also is of such form that the chips will not wedge on reversing, but be cleaned out of the thread.

On many materials it would be found that, providing sufficient taper is allowed on the front of the tap, one tap will be sufficient to complete

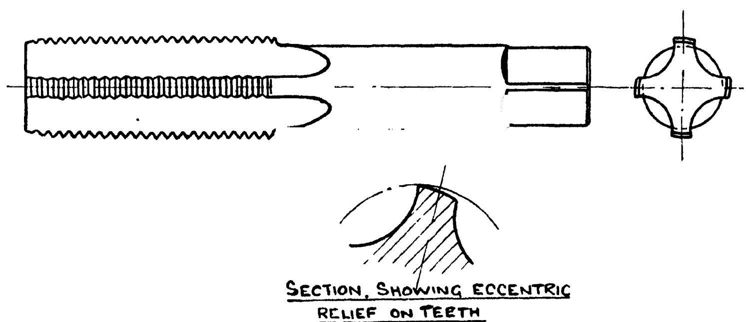


Fig. 15.—CIRCULAR FLUTED TAP

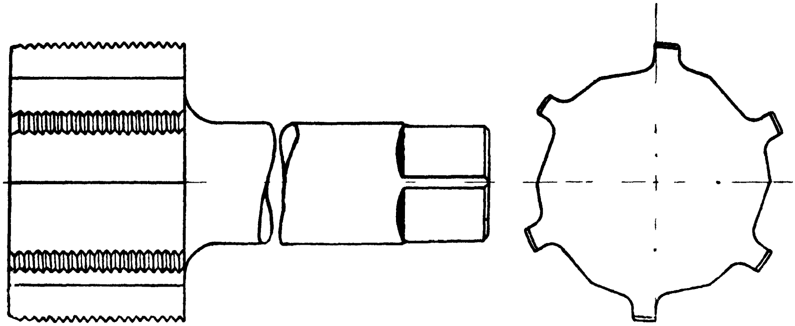


Fig. 16.—Tap for fine threads

the threading operation. On the harder materials, however, and especially on blind holes, it is necessary to use two or three taps, the earlier taps in the set having a longer taper in order to relieve the cut. On very hard material an advantage can be obtained by making the preliminary taps small on the effective diameter.

For instance, if two taps are being used in the set, number one can be made minus ·015 in. on all diameters, so roughing out the thread undersize before the finishing tap is passed through. This arrangement is very effective when the nature of the material being tapped is such as to cause the tap to cut oversize.

Fine-thread Tapping

When tapping fine-pitch threads in cast iron, aluminium, and Elektron metal, the width of the thread portion must be cut down considerably (Fig. 16) and the threads should not be relieved. This unrelieved thread is particularly necessary when the tap cannot pass through the work and has to be reversed for extraction. The narrowness of the threaded portion keeps friction to a minimum and, because the threads have unrelieved full diameter, there is no space between the threaded portion of the tap and the work into which the very fine particles which can be expected from cast iron and light alloys can find room to become wedged, so binding the tap and tearing out the fine threads.

Nut Taps

Fig. 17 depicts a type of tap generally in use for nut tapping. It is two-fluted, so allowing more space for chip clearance ; it is tapered for a considerable distance on the front, and also the leading teeth are ground back slightly, so providing a helical lead. This has the effect of thinning the threads gradually towards the front of the cut, so that the total

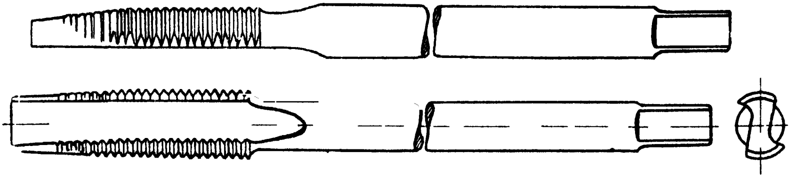


Fig. 17.—Two-fluted nut tap

width and depth of cut are taken up gradually. Considerable front cutting rake is provided up to 25°.

Whilst this type of tap is quite satisfactory on soft steel nuts, it will be found that on the higher tensile heat-treated steels, such a tap will almost inevitably cut oversize and a four-fluted tap, as shown in Fig. 18, will be necessary. These taps are made long so that a number of pieces can be tapped before it becomes necessary to remove the tap from the machine to free the components. It will be noted that on the four-fluted tap a pilot portion is provided to pilot the tap in the already drilled hole. The front cutting rake should approximate 10°.

Taps with odd numbers of flutes are to be avoided because of the difficulty encountered in measuring the diametral dimensions. Special machines for tapping nuts will require taps made of a design peculiar to the machine, the difference being usually in the shape of the shank only.

In factories using a wide range of material for their product, much difficulty is usually experienced in making taps cut to size within the tolerance allowed on the threaded hole, and it is found necessary, in order to obtain accuracy, that taps are available which vary in size in proportion to the tendency of the material either to hug the tap during operation and produce small holes, or cut freely and produce holes larger than the size of the tap itself.

Elektron metal is one example of material which hugs the tap, and it will be found that in order to produce " size " holes, the effective diameter on the tap must be increased ·003 in. above the top limit of the tolerance. Such taps on becoming undersize on this material can be used subse-

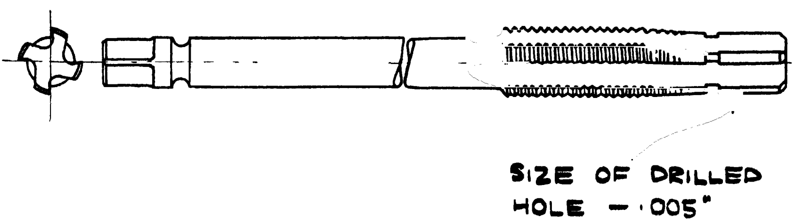


Fig. 18.—Four-fluted nut tap

quently on cast iron and aluminium. It is, of course, necessary that the front cutting edges are reground to a positive cutting rake, as taps for Elektron metal are made with a small negative rake amounting to a few degrees.

When accuracy is required on long tapped holes in steel, it is often found advisable to use taps without form relief because pitch error is almost unavoidable on a long thread, when form-relieved taps are used, which, owing to their keen cutting qualities, tend to cut a path for themselves, so deviating from the true lead.

Large-threaded Taps

The set of four taps depicted in Fig. 19 is used for tapping large brass nuts. All the dimensions required for their manufacture, together with details of the thread being tapped, are included in the illustration.

It will be noted that the last three teeth on all four taps are not relieved either on the outside diameter or on the flanks of the teeth. This is necessary to ensure that any one of the set will be small enough at the start to follow the tap previously passed through the hole. This would not be possible if all the threads were relieved and excessive grinding had taken place on one of the taps, resulting in the threads being undersize and too small for the succeeding tap to enter.

To relieve the cutting load most of the teeth are stepped, and it will be noticed that the first few teeth of No. 1 tap are much narrower, being only 40 per cent. of the required width. The next teeth are full width and unstepped so ensuring that the taps follow the correct lead from the start.

It is necessary to pass these taps completely through the work, and it is usual when they are used on combination turret lathes for them to feed themselves through by hand-operating the turret without the necessity for providing a lead screw of the required pitch. They are passed through the work and through the machine spindle, arrangements being made for supporting them as they come through the bore of the spindle at the far end.

As a guide to the operator, so that he takes up the taps consecutively, rings are turned around the shank of the tap, the number of rings corresponding with the sequence number of the tap. If, even after having given the greatest attention to the design of taps, indifferent results are obtained, it is always advisable, before making any change in the taps themselves, to study the question of the cutting lubricant, which plays an important part in the satisfactory working of taps. Different materials will react favourably to specific lubricants, but for general purposes rape oil will overcome many tapping troubles.

When dimensioning machine-cut taps unground and unrelieved on the threads, they should be made larger on the effective diameter than

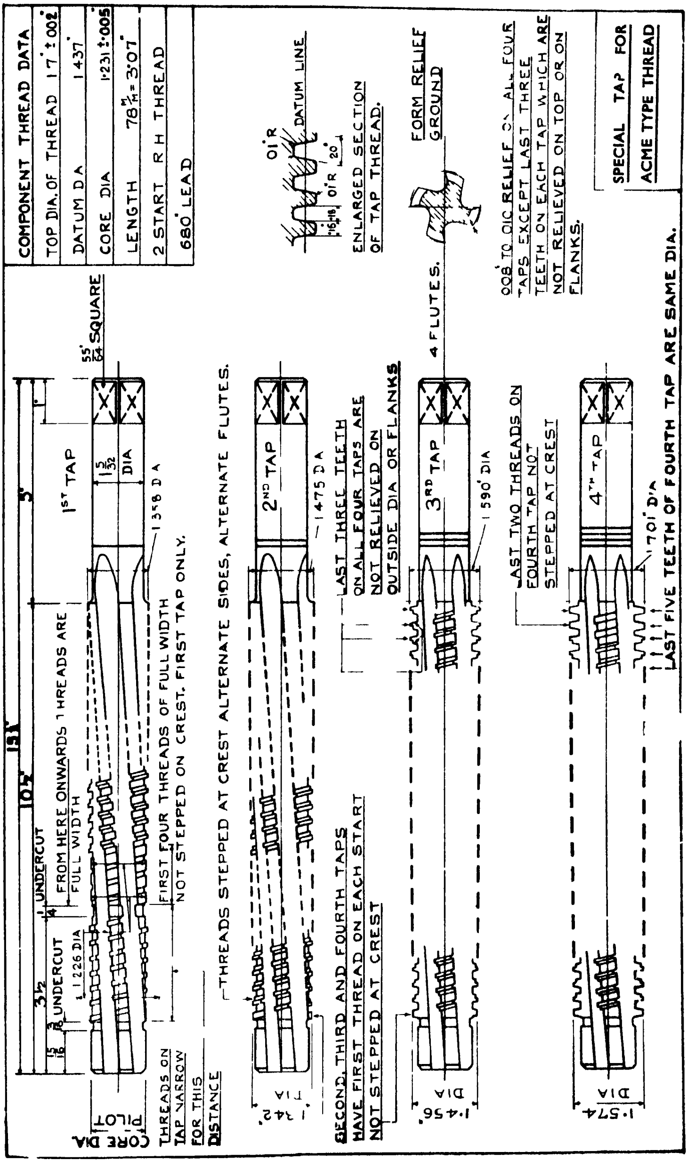


Fig. 19.—SET OF FOUR TAPS FOR ACME THREADED NUTS

relieved taps, because, not being so free cutting, they rarely cut larger than their own dimensions. The following chart gives a comparison between the tolerance required on the tapped holes which, for illustration, has been taken as the Wickman "M" tolerance, and the dimensions from actual practice of ground thread form relieved taps and machine-cut unrelieved taps.

Threads per Inch	*Wickman "M" Tolerance*	*Tolerance for Ground Thread Form Relieved Taps*	*Unground Machine cut Taps*
	In	*In*	*In*
26	+ 005	+ 0013	+ 004
	− 000	+ 0004	+ 001
24	+ 0055	+ 0013	+ 0045
	− 0000	+ 0004	+ 0015
22	+ 0055	+ 0013	+ 0045
	− 0000	+ 0006	+ 0015
20	+ 006	+ 0013	+ 0045
	− 000	+ 0006	+ 0015
18	+ 0065	+ 0013	+ 0045
	− 0000	+ 0006	+ 0015
16	+ 0065	+ 0013	+ 005
	− 0000	+ 0007	+ 002
14	+ 007	+ 0013	+ 0055
	− 000	+ 0008	+ 0025
12	+ 0075	+ 0018	+ 006
	− 0000	+ 0008	+ 003
11	+ 008	+ 0018	+ 006
	− 000	+ 0009	+ 003
10	+ 0085	+ 0019	+ 0065
	− 0000	+ 0011	+ 0035
9	+ 009	+ 0021	+ 0065
	− 000	+ 0012	+ 0035
8	+ 0095	+ ·0022	+ 007
	− 0000	+ 0014	+ 004

Care must be taken also with the size of the drilled hole; some materials tend to build up, due to the pressure of the tapping operation, thereby closing the hole, whilst others which can be freely cut do not show this tendency. Dimensions for satisfactory sizes are given in the section on drill bushes.

Chapter VI

MILLING CUTTERS

WHILST the majority of the small tools described so far have been so specialised that the tool man may not be called upon, except on few occasions, to design them, and although plain and simple milling cutters are also to some extent standardised, the multiplicity of varying requirements of this tool are such that it is safe to say that every tool draughtsman will be called upon, on many occasions, to design some type of milling cutter, and it is therefore essential that he understands the principle underlying correct design.

Fig. 1 shows the correct design for a slab or roller mill. In this type of cutter the teeth are always helical, otherwise the full width of the blades would meet the work at the same moment, causing such hammering, particularly on shallow cuts where only one tooth is in contact with the work at one time, that damage both to the cutter and machine would be probable and the finish on the work poor.

Although roller mills are sometimes made for heavy hogging work with helical angles of around 70° with only three teeth or starts in a 4-in. diameter cutter, the best angle for general purposes will be around 20° ; this angle is steep enough to permit more than one tooth to be in contact with the work at one time, preventing hammering and sufficient also to provide a shearing cut, so avoiding the necessity for the nicks being ground in the teeth to act as chip breakers.

The use of chip breakers is to be avoided. At one time these were extensively employed, but it has been proved that cutters dull quicker at the edges of the grooves and also that there is a tendency to break away at the corners. If on a very wide cut it is found that chattering occurs, then chip breakers may be necessary and should be designed as Fig. 2, with the notches undercut.

Rake

Rake or undercut is important, and by tending to make the cutter cut or shear off the chip instead of partly pushing it off, as would be the case if the cutting face was radial from the centre of the mill, it will be found that 50 per cent. more metal per h.p. will be removed than is possible with the cutter without rake.

This undercutting to provide rake will weaken the tooth unless

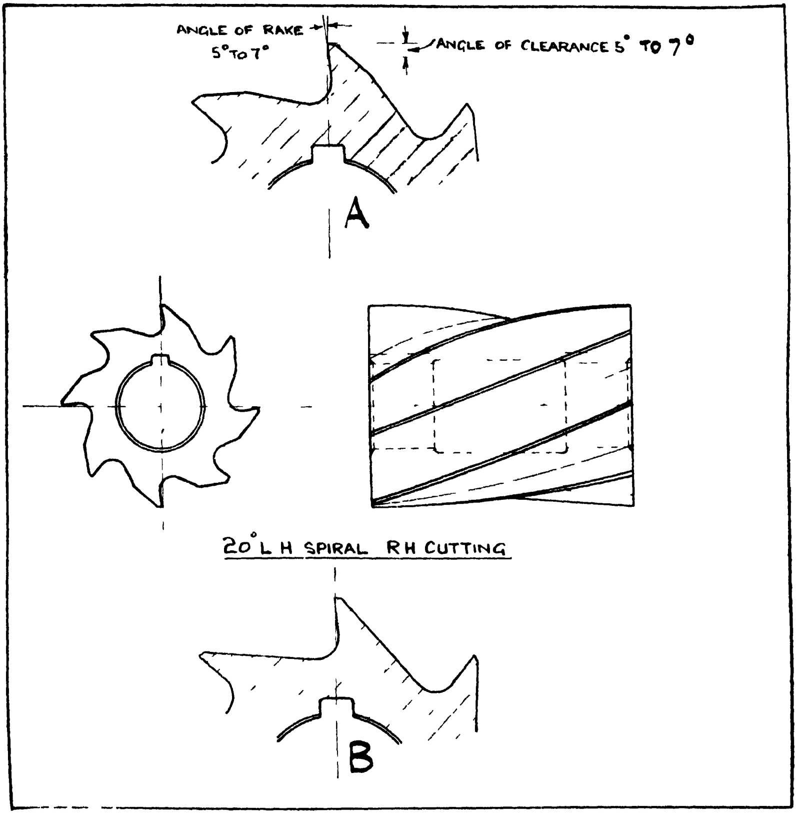


Fig. 1.—ROLLER MILL

the back of the tooth is formed to counteract this, as at *A*, Fig. 1. This is done effectively by making two cuts to form the back of the tooth instead of one, as was the earlier practice, as shown at *B*, Fig. 1. The clearance behind the cutting edge should be between 5° and 7°.

The fillet or radius at the bottom of the tooth should be as large as practicable, thereby curling the chips and preventing them from clogging in a corner and spoiling the finish on the work by interfering with the cutting edges. The bore, if the cutter is over 2 in. in length, may be relieved in the centre and, together with the driving keyway, should be to the factory standard or, better still, the National Standard.

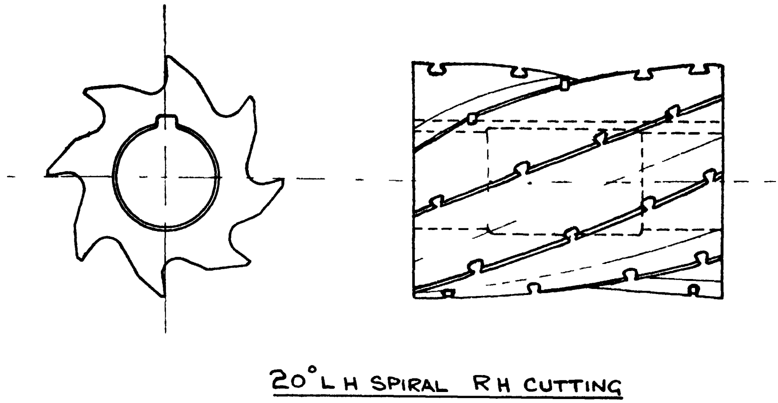


Fig. 2.—ROLLER MILL WITH NICKS TO BREAK CHIPS

Side or Straddle Mill

The type of milling cutter as shown in Fig. 3 is a general-purpose mill and can be used for milling faces with a ledge beneath, or a slot, or in gangs for milling either side of one or more bosses at the same time. Similar undercutting is required as was the case with the roller mill, although the necessity for forming the back of the tooth by taking two cuts is not so necessary. The teeth, being less widely spaced than the roller mill, are strong enough, as a rule, without this precaution. The two side faces of this cutter are recessed to allow for grinding the sides of the teeth when resharpening.

When cutters of this nature can be laid down for a large quantity of components, it is better to design them for the specific purpose. For instance, if the cutters are required for heavy straddle-milling operations, it would be advisable to design them in pairs, so that instead of the front teeth being cut square, they are cut right hand on the one cutter and left hand on the other, so obtaining a distinct cutting angle on the one edge of each cutter. In this way higher feeds can be obtained and a better finish results.

Interlocking Cutters

Should a cutter be required for machining a gap or slot, the width of which must be maintained, then it is advisable that it be designed as in Fig. 4, which provides rake in every direction by making the cutter in two pieces, the peripheral teeth being cut right and left hand respectively, so obtaining rake to the two outer cutting edges. The two halves of this cutter are made to interlock in order that there may be no flash or ridge left on the work between the two cutters, as would be the case if they were placed flush side by side. After regrinding, the width is maintained

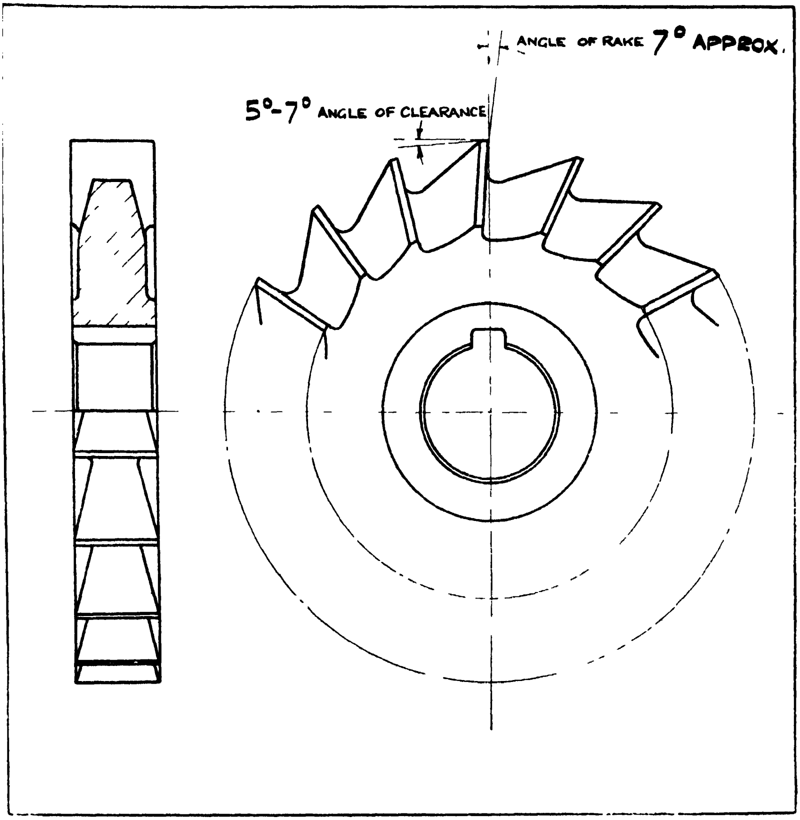


Fig. 3.—SIDE AND FACE MILLING CUTTER

by inserting a distance washer between the inside bosses on the cutter. It is advisable to arrange the interlocking jaws between the two cutters so that the teeth are interspaced.

End Mills

End mills (Fig. 5) vary considerably in design and are not so subject to set principles as the majority of other types of milling cutters. The work performed by end mills is usually of a light character, and designing for heavy cutting is not so important. The end mills shown at *B* conform to the usual accepted principles. This type of cutter is designed for the heavier class of work and is arranged with a tapped hole at the end of

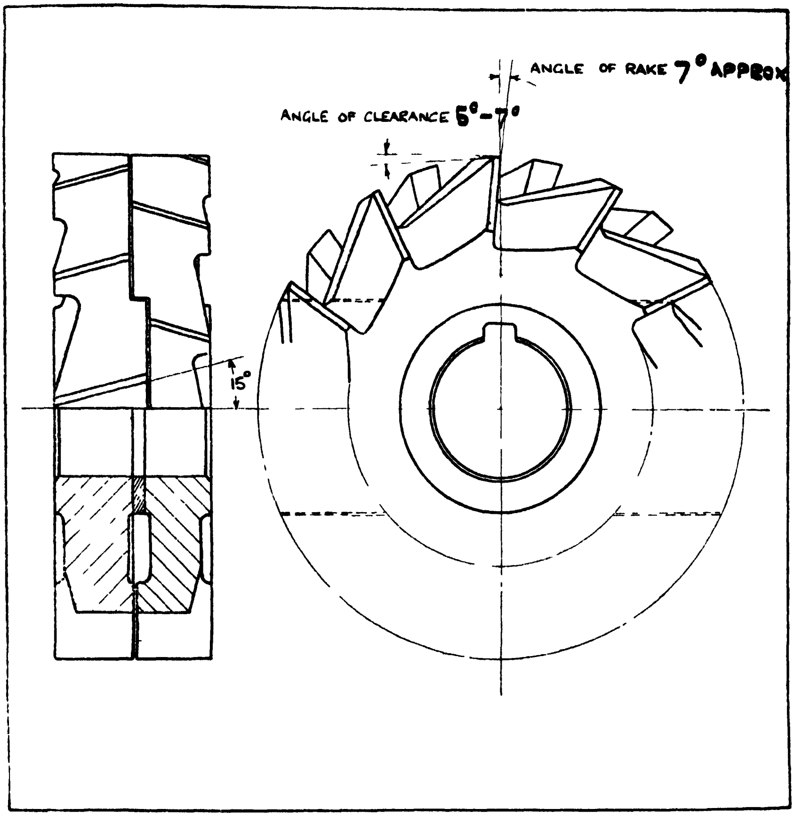


Fig. 4.—INTERLOCKING CUTTERS

the shank so that the cutter may be firmly held back into its socket. The blades are made with a right-hand spiral, usually not more than 20°, and have a front cutting rake of 10°, thereby giving rake in all directions.

This type of cutter is not so easily or quickly inserted into the machine spindle, because of the necessity for tightening the drawbar through the spindle. For this reason end mills are often designed with left-hand spiral blades, the action of the cut then tending to force the cutter into the socket and not pull it out, as is the tendency with the right-hand spiral.

With the left-hand spiral cutters shown at *A* and *C* the spiral angle is kept below 10°, and the front cutting rake should not exceed 7°. It will be noticed that the teeth of the cutter are continued across the end,

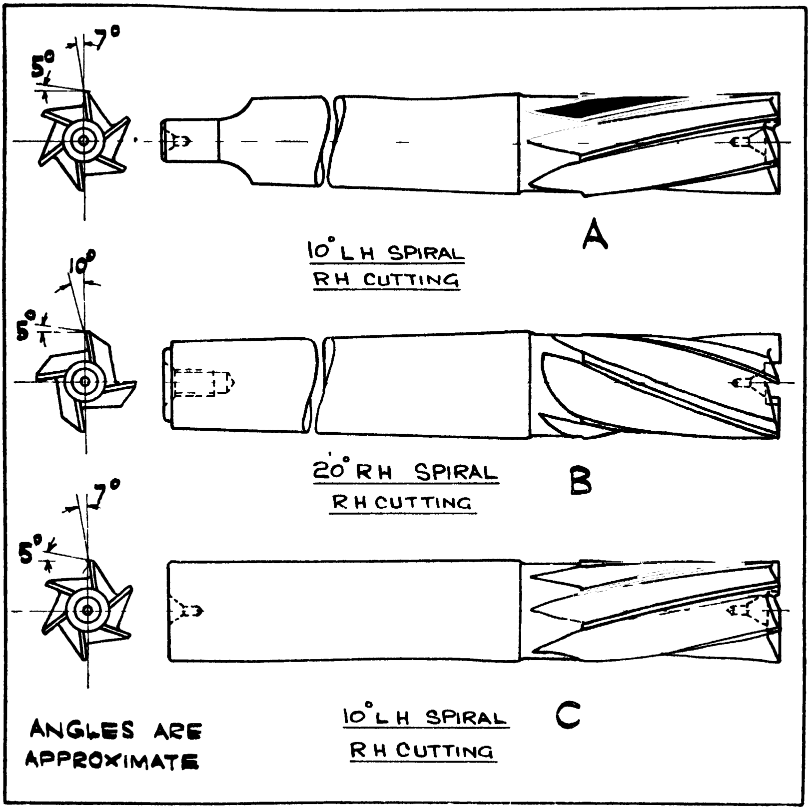


Fig. 5.—END MILLS

and, in order to facilitate the grinding, a counterbore is arranged into which the teeth are cut. The cutter shown at *A* is driven by the tang and has a standard taper shank, whilst the cutter *C* is of a type suitable for holding in a chuck.

Shell-end Mills

Fig. 6 shows an example of a shell-end mill. On larger diameter end mills it is usual to make them of this type, otherwise the cost of the steel for making the cutters integral with the shanks is excessive. The shank is therefore made in some good-quality steel, heat-treated, and the cutter is fitted on the end of this and held in position by a bolt and a washer which sinks into the counterbore on the end cutting faces. The

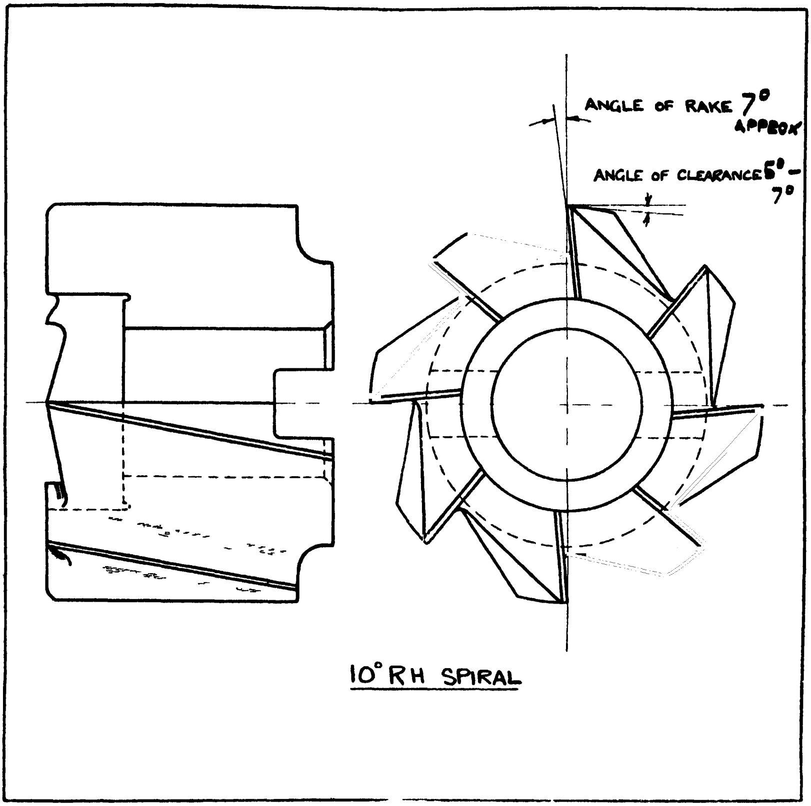


Fig. 6.—SHELL-END MILL

drive is taken by a key slot milled across the cutter through keys fitted into the shank.

This type of cutter is usually used for surfacing and is not, as a general rule, employed for milling on its side face as a vertical roller mill. The cutting will therefore be done mostly around the end of the cutter. To keep the end teeth as strong as possible, the spiral angle should not be greater than 15°. Should a side-milling operation be required, however, then this angle can be increased to 20°, similar to that on the roller mill.

Face Mills

When over 3 or 4 in. in diameter the shell-end mill is usually termed a face mill, and because of the cost of the high-speed steel which would

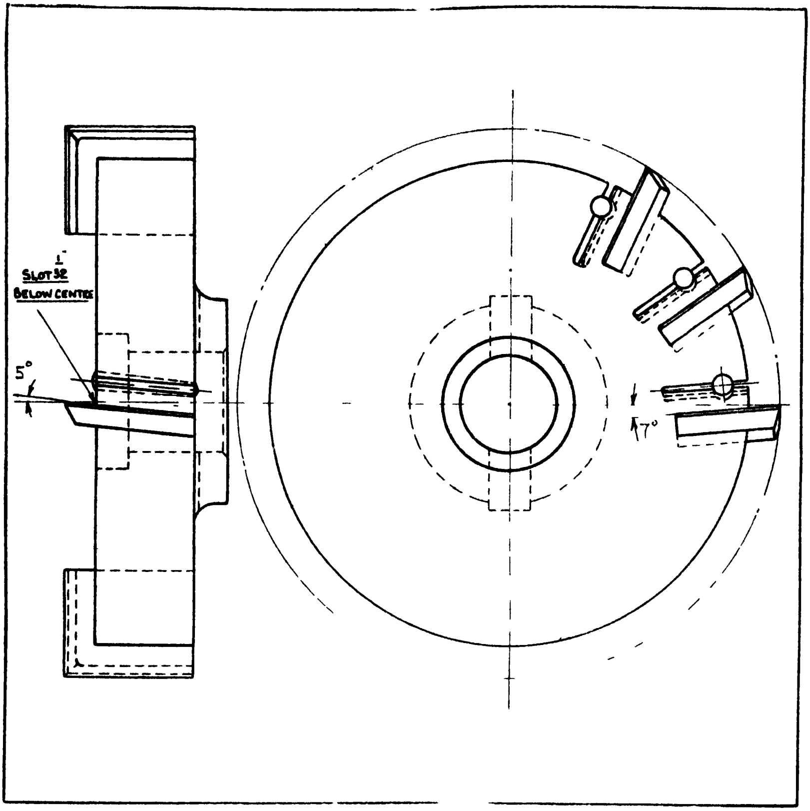


Fig. 7.—Face mill

be required for making a solid cutter, blades of the cutting material are inserted into a body of a cheaper material. Fig. 7 shows a much-used type. A saw cut is made approximately $\frac{5}{16}$ in. in front of the cutting edge of the inserted blade, cutting through a taper hole previously drilled and reamed at a reasonable distance from the edge of the blank. A taper pin driven into the hole presses a part of the blank against the cutter, so holding it firmly in position. Variations from this arrangement occur, such as a parallel pin with a taper flat-machined on one side being driven tight against the cutter face. Many patents and peculiar devices are employed by various manufacturers of this type of cutter, but perhaps the simplest and most economical is that described above.

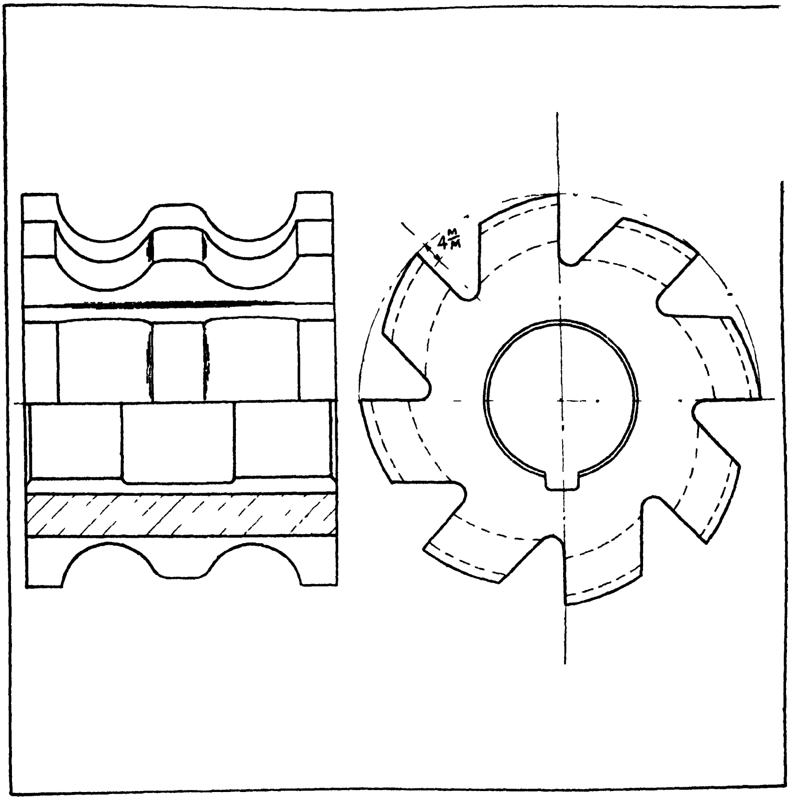


Fig. 8.—Form-relieved cutter

Form-relieved Cutters

Fig. 8 shows an example of a form-milling cutter which is backed off or relieved in such a manner as to maintain the accuracy of its form after regrinding. This type of cutter is relieved on what is known as a relieving lathe and which has a cam-operated tool slide. Cams are available to give various depths of relief to cutters, this depending chiefly on the work for which a particular cutter is required. The example shown has a relief of 4 mm. By relieving the cutter in this manner the cutting form is maintained right through the tooth. When sharpening the cutter, the teeth are ground on the front only and the cutting form is not interfered with.

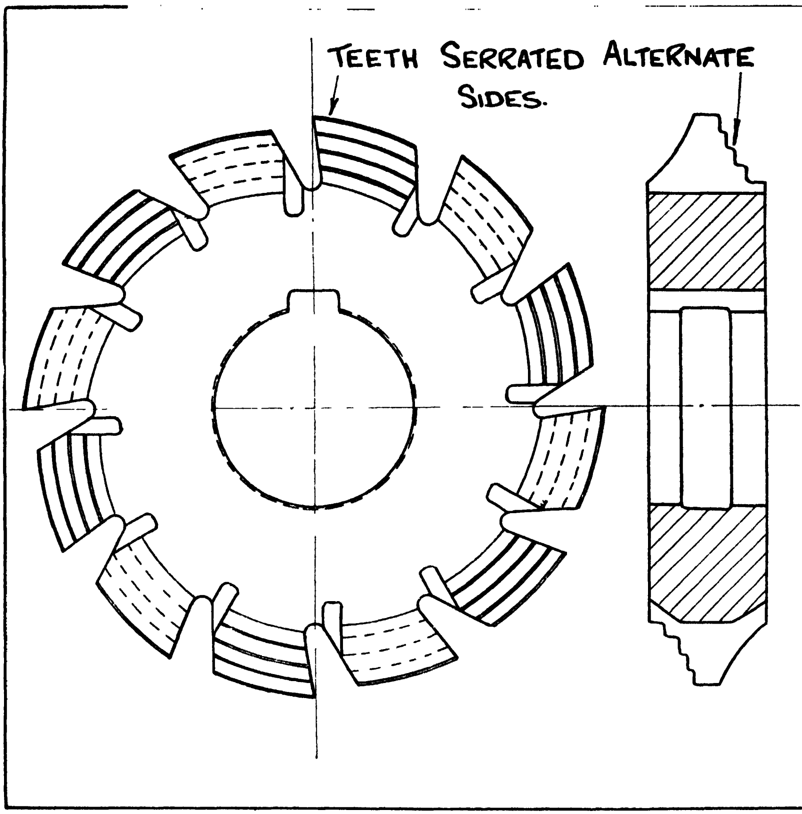


Fig. 9.—FORM-RELIEVED CUTTER WITH SERRATED TEETH

Another factor determining the amount of relief will be the number of teeth and the distance from one tooth to another. Form-relieved cutters should never be designed with too few teeth, because the whole profile usually meets the work at one time, thereby causing very heavy hammering on the tooth. It will be seen, however, that for milling a deep form the teeth must be made correspondingly coarse to obtain the required strength of tooth.

Whenever possible alternate teeth should be serrated as shown in Fig. 9. This serves to break up the cut and reduce hammering. Tests have shown that cutters so made will produce twice the amount of work between regrinds.

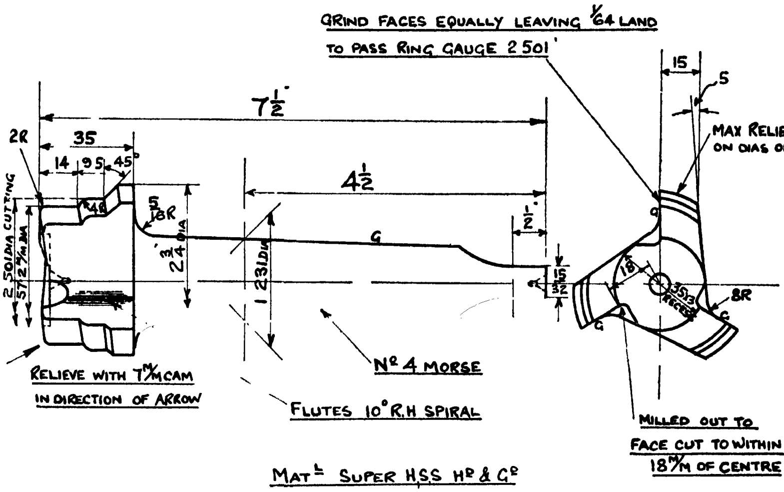


Fig. 10.—FORM-RELIEVED COUNTERBORING CUTTER

Form-relieved Counterboring Tools

The form-relieved tool is a type of tool often poorly designed. The examples which follow are attempts to indicate the direction in which improvement can be made. The principal considerations when laying out tools of this type are that form is maintained after each regrind, positive cutting rake is provided, and that the " life " is such as to make the tool as economical as possible

Fig. 10 shows a spirally relieved end cutting form tool used to produce a series of counterbores at the end of an already bored hole. The cutter is three-fluted, and because of the spiral relief has positive cutting edges on the front cutting faces as well as on the outside diameter. A tool such as this is adequate when there is a large tolerance on the diameters of the counterbores ; it will be realised that each time the tool has to be reground on the faces marked *G*, the cutting diameter of the tool is reduced, the cutter becoming scrapped when the low limit of the counterbores required is reached.

Fig. 11 illustrates a tool more costly to produce, but which has the advantage that, where close limits are required, size can be maintained throughout the life of the tool. This example is used for a recessed face occurring at a shoulder some way down a turned diameter (Fig. 12). The bracket holding the tool is fitted with a sleeve carried on two ball races which serves as a steady for the already turned diameter. The cutter is spirally relieved and has two teeth, one cutting the internal diameter and the other the external diameter. On the front of the bracket

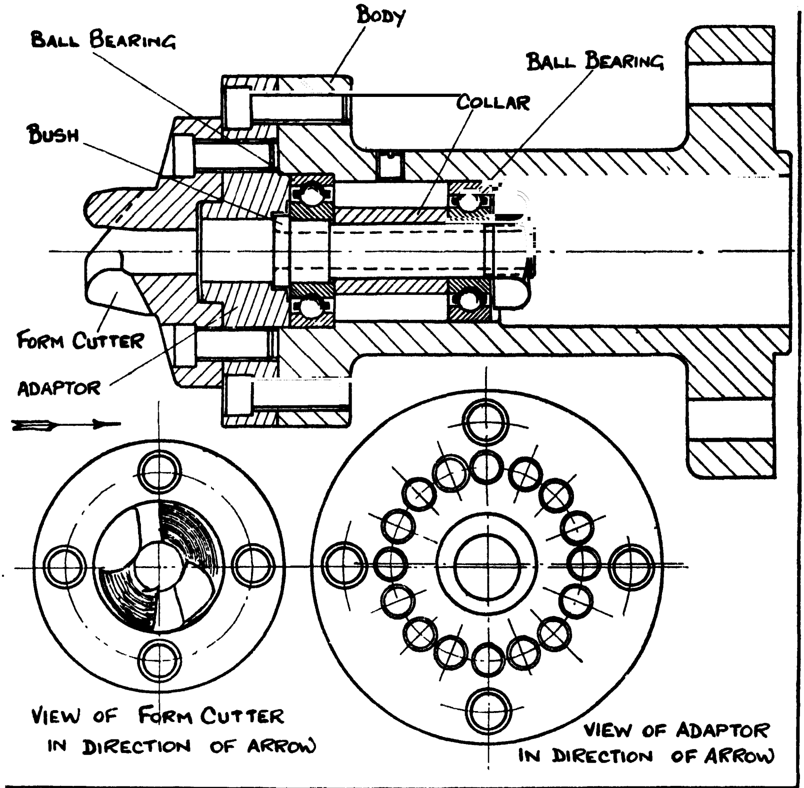


Fig. 11.—FORM CUTTER WITH COMPENSATION ON DIAMETERS

is a register and a circle of equally spaced holes eccentric by ·015 in. to the running bush.

The tool on being reground can be rotated a small amount around the eccentric spigot and clamped by the four screws into the nearest holes which coincide with those in the cutter, with the result that the side of the tool cutting the internal diameter is increased and that cutting the external diameter reduced by an equal amount.

Lathe-form Tools

Fig. 13 is an example of a circular-form tool for an automatic machine. A feature of this example is that the form is spirally relieved at a lead of

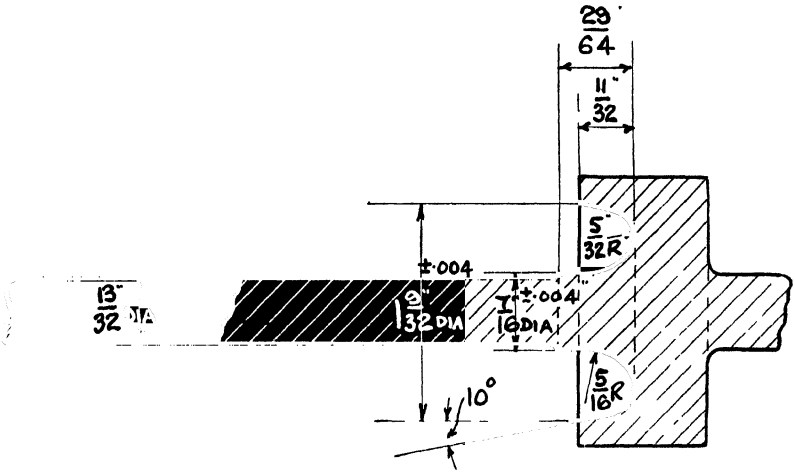


Fig. 12.—Groove produced by cutter in Fig. 11

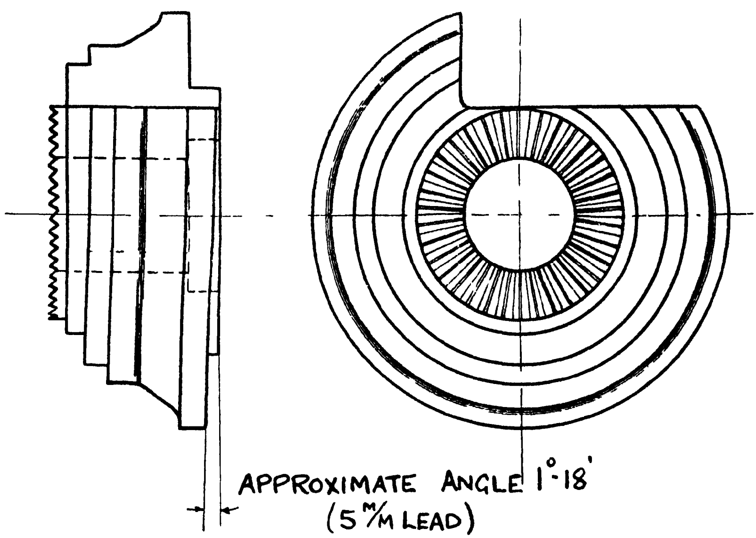


Fig. 13.—Circular form tool

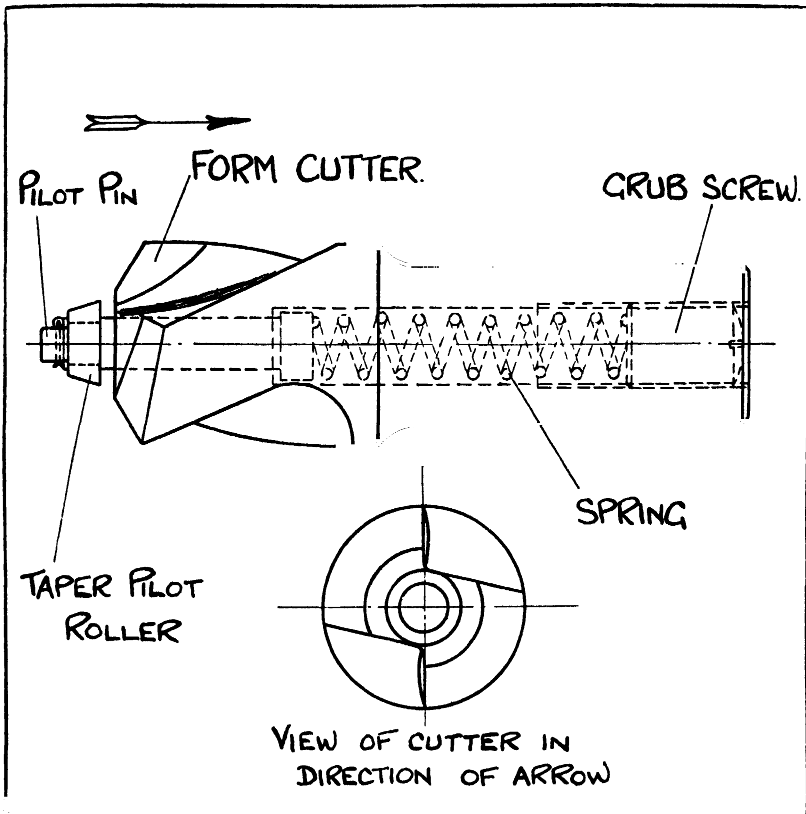


Fig. 14.—PILOTED FORM TOOL

approximately 5 mm., so providing a positive cutting clearance on those parts of the tool which would be employed in turning the faces. Without helical relief these positions would be rubbing and not cutting. The advantages of this method are not generally appreciated, and because this type of relief is no more costly to produce, all tools required for forming on one side only should be so made.

The cutting face is shown below the centre line, the tool being set in the machine so that the cutting edge is brought up to the centre line of the work, so providing front clearance. By so doing, however, the effective form of the tool is changed and where accuracy is required a compensated form is necessary. Methods for developing this correction are explained later The serrations on one side of the tool are standard

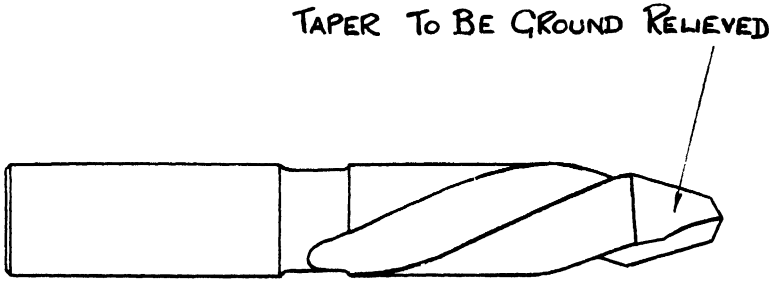


Fig. 15.—Tool for forming a taper from a drilled hole

and serve to lock the tool securely into the tool-holder and to prevent it moving under the cut.

An interesting application of a form-relieved tool and one which has to pilot in an already finished taper hole is shown in Fig. 14. It has two blades, the chamfer and front cutting face being form-relieved. Because it is necessary for the cutter to pilot within the taper hole, a tapered roller is fitted in front of the cutter and is free to revolve on a spring-loaded pin, a good sliding fit within the body of the cutter itself. If the hole already in the work had been parallel, the spring loading would have been unnecessary, but the arrangement shown permits the tool to feed into the work after the tapered roller has seated itself in the finished taper bore.

Fig. 15 shows a tool which forms a taper from a drilled hole and has given very satisfactory finish and performance. It will be seen to be a development from a drill, but has been specially made. Being spirally fluted, the swarf is cleared away from the cutting edges very rapidly. Front cutting rake is provided by the shape of the fluting.

An example of a flat-form tool for use in a lathe is shown in Fig. 16. This tool is made in pairs, right and left hand, and is used for finishing both sides of a deep groove as shown in the figure. Each tool consists of a high-speed steel cutter, which is mounted on to a toughened steel shank by means of two screws. In order to hold the tool in line whilst cutting, a key is sunk partway into the shank and the projecting portion of the key engages a slot cut in the underside of the cutter. This key is essential on all tools of this type to ensure that the cutter is held rigidly in position.

It is interesting to note that this tool is relieved to give a constant cutting form when regrinding. This is achieved by making the tool to a form gauge which is applied to the tool along the line *A–B*. The gauge is applied to give a front clearance of 10° to the tool on the section *AB* as shown. It will be seen that this 10° angle will also apply on any section of the tool parallel to *AB*, but that the actual clearance angle

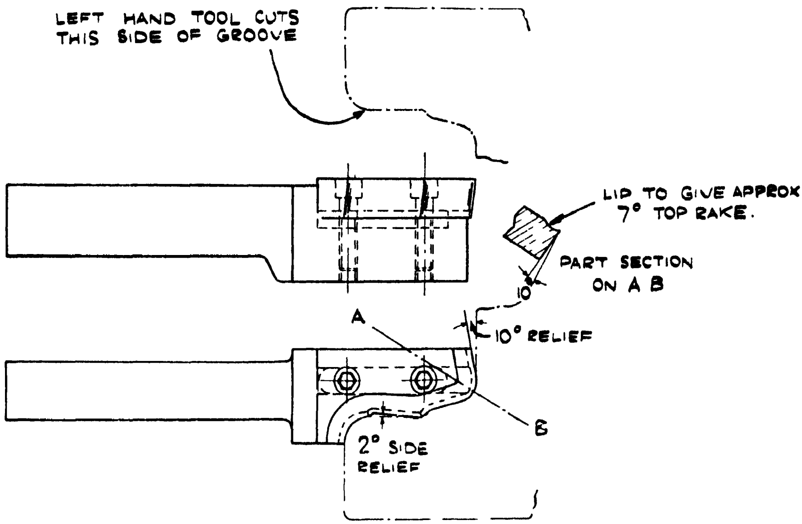


Fig. 16.—Flat-form tool

will vary slightly round the cutting edge and would become zero on a section at right angles to AB. For this reason the line of application of the form gauge should be selected to give, as near as possible, an average front clearance all round the cutting edge. In order to provide a top rake on the tool, a lip is provided which follows the contour of the cutting edge and leaves approximately ·005 in. land on this edge. This lip is ground in the tool by means of a small wheel, and although this may appear to be an expensive operation, the toolroom grinder will, with practice, become quite proficient. The tool is resharpened by grinding the top face on a surface grinder and then regrinding the lip.

Chapter VII

MULTIPLE AND CONSECUTIVE TOOLING

KNOWLEDGE of the tools described in previous sections will enable the tool man, when called upon, to design what are known as multiple tools, which, as the name implies, are used for performing more than what is normally one operation at the same time. Fig. 1 shows a section of a casting surrounding the inlet and exhaust valve seats and valve guides on an internal-combustion engine and also the tools used for completing the machining operation. The tools described are those used for the exhaust ports, those used for the inlet ports varying only in small detail.

Multiple Drilling Machine

A twenty-four-spindle multiple drilling machine, with twelve of the spindles forming a rear row and twelve a front row, six of which in each row are used for the inlet valve seats and six for exhaust valve seats, is used in this instance for the operation. *A* shows the combination tools used in the back row, and these remain permanently set in the spindles. In each of these tools three separate cutting tools are incorporated. It will be noticed that the throat in the valve port converges towards the centre of the valve guide hole, and because of this a flat facing tool is used to provide a clean and flat face from which the subsequent drilling can commence without the bias which would be occasioned in consequence of starting the drilling on an irregularly cast surface. Above this is the tool which roughs out the throat and, superimposed, a tool for roughing the valve seating. On top of this is a square cornered tool for roughing out the counterbore in readiness for an inserted valve seating. After the first operation, on the back row of spindles, the component is moved forward to the front row. The various tools are changed in the front row only, so permitting one set of tools to remain permanently set in the machine, and those tools which have to be changed are accommodated in the most convenient position for the operator. The tools in the front row are used in the following seq nce :

The valve guide holes are drilled first as shown at *B*, with all twelve spindles. The drills are removed and twelve combination tools, *C*, inserted in their place ; these finish the valve seatings and the throat and semi-finish ream the valve guide holes. The tools are then removed and a final reamer, as shown at *D*, completes the operation. The semi-reaming tool at *C* cuts as a single-point boring tool—very useful when perfect alignment is required.

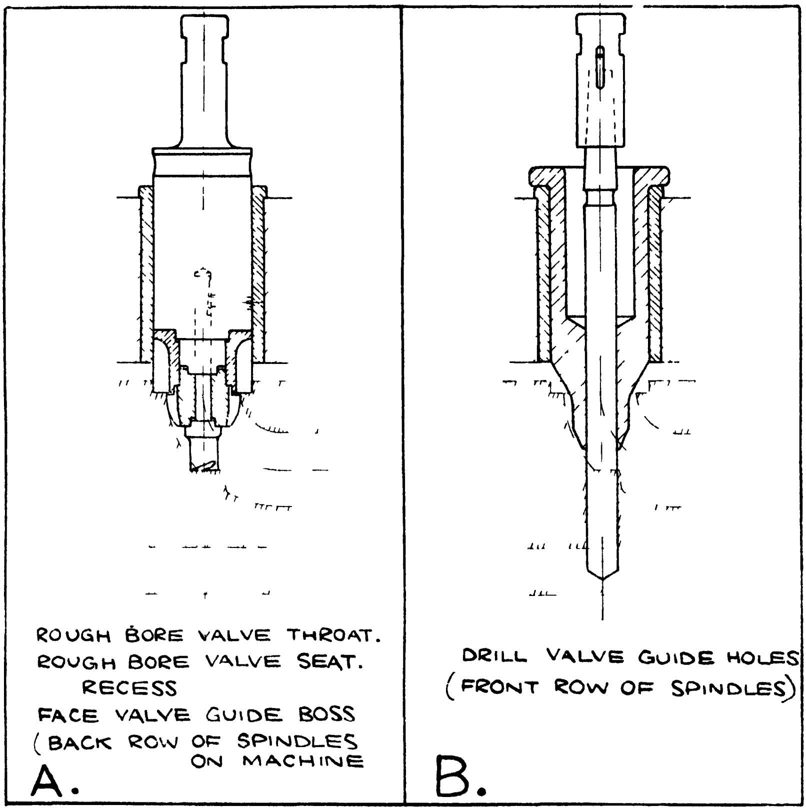


Fig. 1.—MULTIPLE TOOLING (A AND B)

It will be observed that none of these tools are provided with stop collars to control the depth to which they cut—a necessary feature on most counterboring and recessing tools. The reason for this omission is that on the head of the machine being used for the operation is clamped a dial indicator, the anvil on which meets a pin provided on the jig. The depth of cut is read on the dial, the feed being continued until the " hand " rests on a predetermined mark.

Consecutive Tooling

When a high degree of accuracy is required in a hole composed of several diameters at varying depths, an example of which is shown at *A*, Fig. 2, a number of separate tools are required for the work involved,

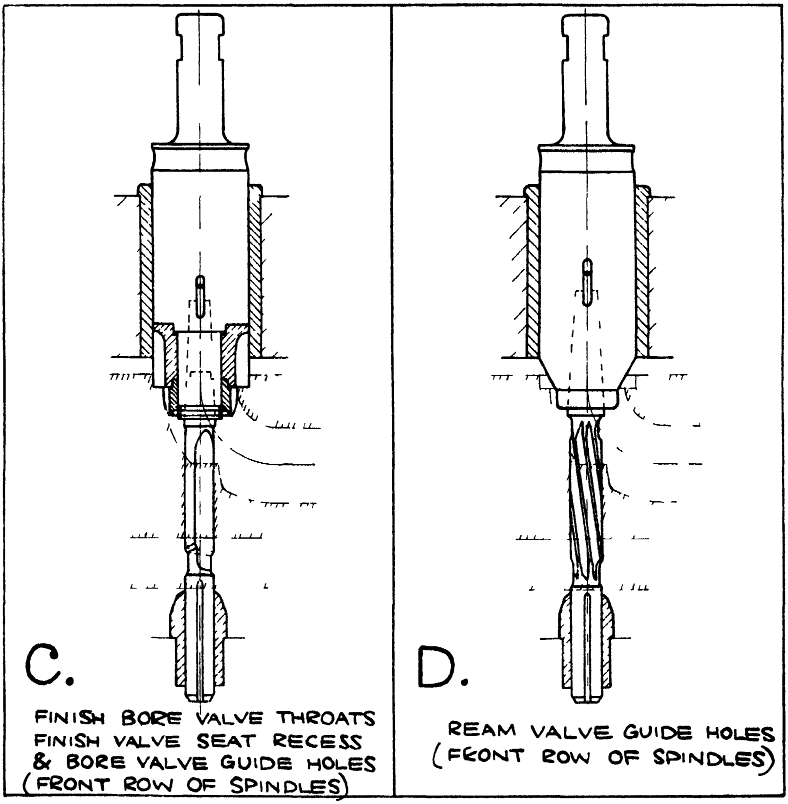


Fig. 1A.—Multiple tooling (C and D)

each, as a rule, preparing the way for the tool which follows and every tool in the set being used in proper rotation. In the instance described, the hole in question has not only accurate dimensions within itself, but its co-relationship with other holes is likewise important. Scrap views, therefore, showing the locations, are included, to show how angular and positional accuracy is obtained.

Below the hole to be machined and pressed into the base of the jig is a guide bush, which is used as a pilot for the tools shown at *B* and *C*, which are required to correct misalignment due to the tendency of the drills, used previously, to run out of truth. Drills cannot be expected, so far away from the guide bushing at the top of the fixture, to maintain alignment within the tolerance required, namely $\pm \cdot 002$ in.

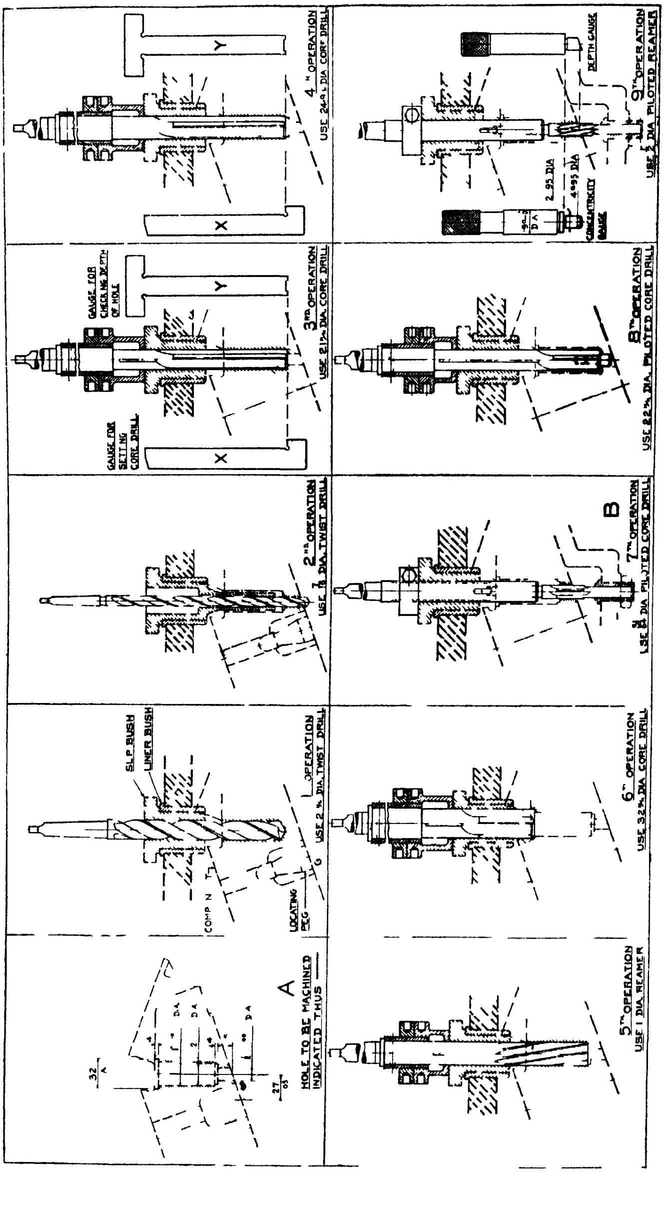


Fig. 2.—CONSECUTIVE TOOLING

Depth of Counterbores

The depth of the counterbores must also be controlled and made "foolproof" for the operator. This is arranged by grinding the heads of the bushes to predetermined dimensions in relation to the work, in order that through the medium of gauges (operations 3 and 4) the locknuts on the tools may be set and adjusted after regrinding to bring the cutting edges of the tool coincident with the component drawing dimensions. By this method the work is machined within the desired tolerance when the face of the lowest locknut touches the top of the bushing. The larger drill (operation 1) is used first so that a guide bush can be inserted to control the direction of the smaller drill (operation 2), and pilot it as closely as possible to its working position. The 21-mm. drilled hole is next flat-bottomed (operation 3) and corrected for depth with the core drill (operation 4), which has been set with gauge X. So that the depth of this hole can be checked whilst the component is in the jig, the gauge *Y* is provided. The correct depth having now been obtained, and in the process the hole increased in size from 21 mm. to 24·9 mm., approximately ·5 mm. remains on the diameter for finishing with the reamer at operation 5.

Following the counterboring operation at operation 6, the smallest diameter at the bottom is corrected for alignment by a core drill (operation 7), which is piloted both at the top and bottom, leaving $\frac{1}{64}$ in. in the hole for subsequent reaming (operation 9), which operation is completed after finishing the 22-mm. diameter (operation 8) by using a piloted core drill, which is guided and steadied at the bottom in the small hole, this being chosen in place of the bottom bushing, so preventing the use of a long unsteady pilot on such a large tool. Any scoring mark made in consequence in the small hole is removed by the final reaming thereof.

It will be noticed that, in Fig. 2, all the tools are shown with standard taper shanks. This is done for the sake of clarity in the diagrams; in actual practice the tapers are fitted with adaptor sleeves to suit quick-change chucks in use on the machine and similar to that shown at *B* in Fig. 1.

Chapter VIII

TOOL CALCULATION AND DEVELOPMENT OF FORM TOOLS

SO many badly dimensioned drawings of jigs and tools are issued to the toolroom that it is thought desirable to devote some attention to examples of constructions which are not easy of measurement and to illustrate how best they may be tackled from the practical viewpoint by offering the formulæ involved in their solutions.

Dimensioning a Tool Drawing

When dimensioning a tool drawing, the draughtsman should have in mind how the part in question will be produced, and should insert on the drawing all the dimensions that the toolmaker will require. It should not be necessary for the toolmaker to calculate dimensions he requires before proceeding with the constructional work on which he is more economically employed. The jig plate shown in Fig. 1 may be used as an example of dimensioning. It consists of a square plate in which it is required to bore six holes equally spaced on a circle. If the plate is to be marked off by height gauge or bored on a jig borer without a circular table, then it will be necessary to give the linear dimensions *A*, *B*, and *C*, and *D*, *E*, *F*, and *G*.

If, however, the jig borer is fitted with a circular table, the holes may be bored from the centre of the circle, and the only dimensions required will be the diameter of the pitch circle (*H*) of the holes and the angular spacing between them—in this case one-sixth of the circle, or 60°. If this second method is adopted, it is recommended that a central hole (*J*) be provided for setting purposes. This hole is known as a reference hole and is in the jig purely for convenience of manufacture.

The checking of a jig can often be greatly simplified by the addition of one or more such holes, particularly where measurements have to be made in more than one plane. For checking after boring the chord (*K*) should be given, this providing a convenient check whichever method of boring is used.

Care should be taken when using tables of logarithms on tool calculations, because these tables give results correct to within a certain number of figures, usually four, five, six, or seven, depending on the extent of the tables chosen for the calculation. Being independent of the decimal point, which is inserted after obtaining a result from the tables, it will be understood that, when calculating a dimension with, say, three figures

in front of the decimal point, it is necessary to use six-figure logarithms in order to be able to rely on the third decimal figure. Likewise, if the fourth decimal figure is to be accurate, seven-figure logarithms must be used. Due to the above points not being fully appreciated, it is easy to introduce errors of several ten-thousandths of an inch, which errors may be serious in certain tool work, as, for example, in the boring of accurate bush centres or in gauge or cutter calculations.

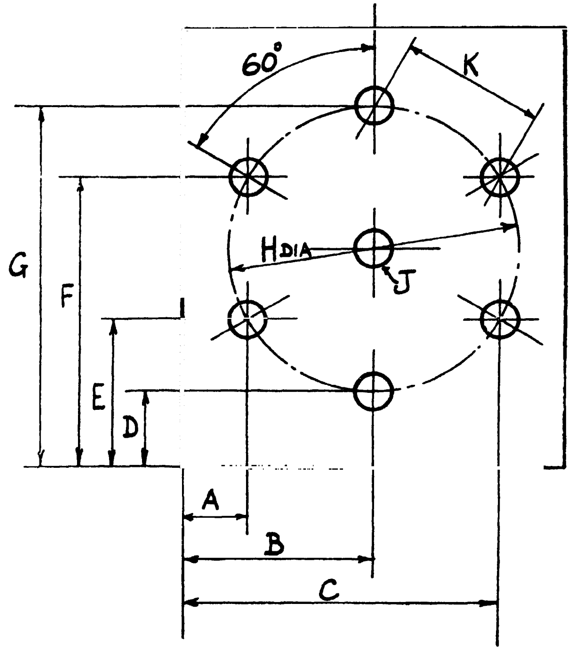


Fig. 1.—DIMENSIONING A JIG PLATE

Spline Cutter

The tool draughtsman is often called upon to design special shaped milling cutters for such operations as spline cutting or worm milling. Fig. 2 shows the method of laying out a spline cutter, the calculations for which are as follows:

$$\sin \beta = \frac{W}{D_1}$$

$$\theta = \frac{\alpha}{2} - \beta$$

$X = D_1 \sin \theta =$ dimension across sharp corners of cutter.

Similarly:

To find checking dimension Y (which may be measured with gear-tooth calipers):

$$\sin \gamma = \frac{W}{D} \text{ and } \delta = \frac{\alpha}{2} - \gamma$$

$\therefore\ Y = D \sin \delta =$ dimension of cutter at top of spline.

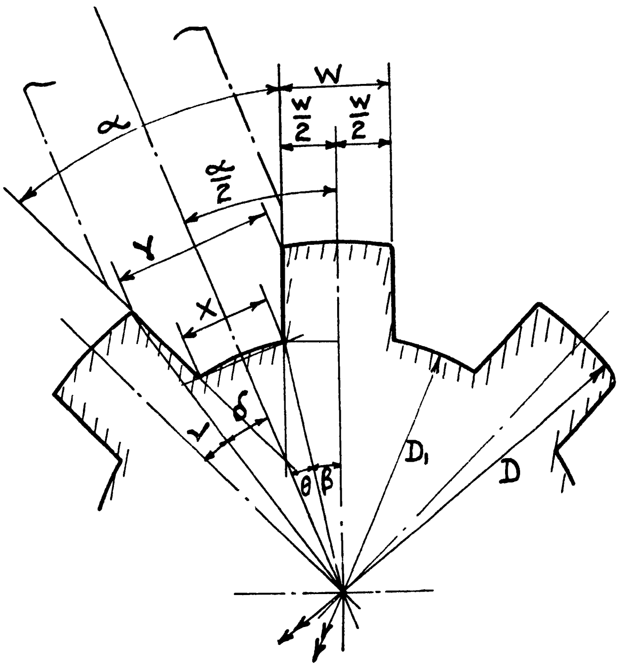


Fig. 2.—CALCULATING CUTTING DIMENSIONS

Marking Off a Large Radius

Suppose it is required to make a template one side of which contains a large radius, which radius may be outside the capacity of the largest trammels in the shop. Such an example is shown in Fig. 3, and it is clearly useless for the tool designer to issue a drawing merely giving the required radius. He should supply a series of ordinates, enabling the template to be marked off. A formula for calculating the ordinates would be developed as follows (referring to Fig. 3).

ABC is a line tangential to the required curve at *B* and is the datum line for marking off the length of the ordinates.

Chord *DEF* is parallel to the datum line *ABC*, and therefore the line *BO* from the point of tangency to the centre of the circle will pass through point *E*, which is a point midway between *D* and *F*.

R is the radius required on the template.

L is the distance of any ordinate from the centre line *BO* of the curve.

h is the height of the ordinate from the datum line *ABC* at distance *L* from the centre line.

$\therefore$ In right-angled triangle DEO,

$$OE^2 = DO^2 - DE^2$$

$$\therefore \quad OE = \sqrt{DO^2 - DE^2}$$

$$= \sqrt{R^2 - L^2}$$

$$\text{Now } h = BO - OE = R - \sqrt{R^2 - L^2}$$

$$\therefore \text{ we have } \underline{h = R - \sqrt{R^2 - L^2}}$$

which may be applied for any required number of ordinates on a radius.

The Use of Standard Balls and Rollers

When measuring and checking angles, it is usual to make use of standard checking balls or rollers, and it is proposed to follow with several examples.

Fig. 4 shows a section of a vee slide, on which type of slide it is usual to machine away the sharp corners, as in the figure. In order that the slide may be checked for width, a dimension should be given across two standard rollers rather than across the sharp corners, which latter dimension can be only theoretical.

Therefore, assuming dimension Y across the sharp corners is known, select two rollers of convenient size and equal in diameter:

Then if

r = radius of rollers
θ = angle of slide
H = depth of slide
and
L = required dimension across rollers

then $x = r \cot \dfrac{\theta}{2}$

$y = H \cot \theta$
$w = x - y$
$\therefore \quad L = Y + 2(w + r)$

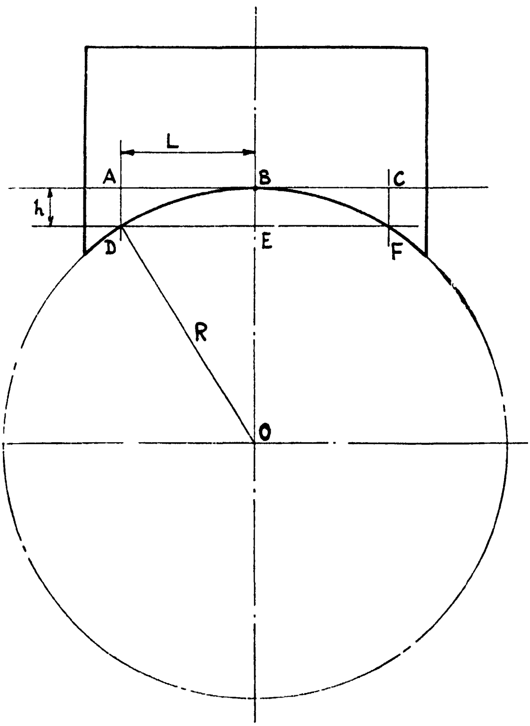


Fig. 3.—MARKING OFF A LARGE RADIUS

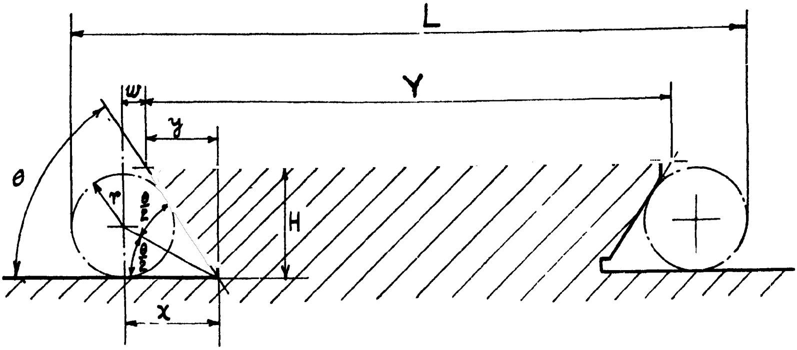


Fig. 4.—CHECKING A VEE SLIDE

In Fig. 5 is shown an angle bracket which has a hole bored at an angle through its vertical face. It is necessary to check accurately the height (h) of the hole from the horizontal face, and also the angle (θ) at which the hole is bored through the bracket.

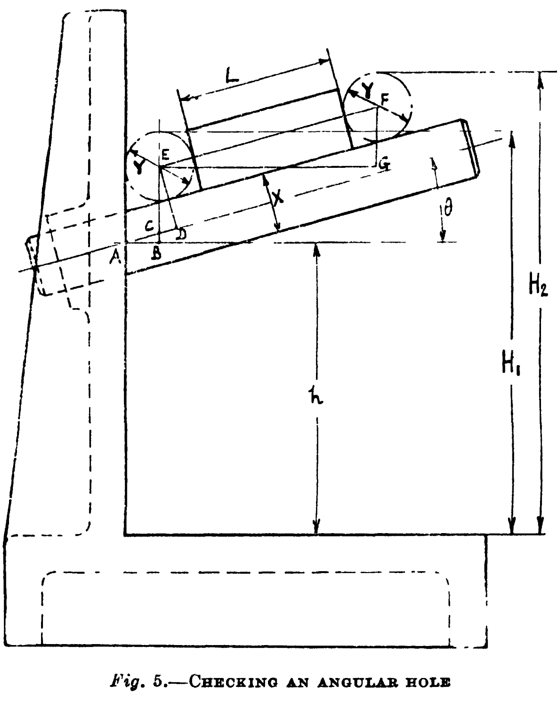


Fig. 5.—CHECKING AN ANGULAR HOLE

The two dimensions may be checked as follows. A plug of the same diameter (X) as the bored hole is pushed into the hole and allowed to project some distance from the vertical face. On the upper edge of the plug are placed two rollers of known and equal diameter, one roller resting against the vertical face of the bracket and the other spaced apart from the first by a reference block of known length (L). Then, being given heights H_1 and H_2, the toolmaker is able to check h and θ :

$\therefore$ **Referring to Fig. 5 :**

$$AB = \frac{Y}{2}$$

$$BC = AB \tan\theta = \frac{Y}{2}\tan\theta$$

$$DE = \frac{X+Y}{2}$$

$$CE = \frac{DE}{\cos\theta} = \frac{X+Y}{2\cos\theta}$$

$$BE = BC + CE$$

$$= \frac{Y}{2}\tan\theta + \frac{X+Y}{2\cos\theta}$$

$$H_1 = h + BE + \frac{Y}{2}$$

$$\text{or } H_1 = h + \frac{Y}{2}\tan\theta + \frac{X+Y}{2\cos\theta} + \frac{Y}{2}$$

$$EF = L + Y$$

$$FG = EF\sin\theta$$

$$= (L+Y)\sin\theta$$

$$\therefore \quad H_2 = H_1 + FG$$

$$\text{or } H_2 = h + \frac{Y}{2}\tan\theta + \frac{X+Y}{2\cos\theta} + \frac{Y}{2} + (L+Y)\sin\theta$$

Another tool frequently requiring accurate checking is the taper plug gauge, an example of which, together with its corresponding ring gauge, is shown in Fig. 6. The angle of the gauge may be checked as shown in the figure. The plug should be centred at both ends and the ends ground square off centres. The equipment necessary consists of two rollers of equal diameter and two bar gauges of equal length. Place the plug, large end uppermost, on a surface plate. Place the rollers on the surface plate, as shown, with their axes horizontal and parallel, and their outside diameters touching the plug at opposite ends of a diameter. Measure the distance $2r$ with a micrometer, the setting of which should be checked with standard measuring slips. Now repeat, but with the rollers resting on the ends of the bar gauges, as shown dotted in the figure, this time measuring the distance $2R$. Then the height of the bar gauge (H) equals the distance through which the roller centres are raised, which, from the equal triangles OPQ, also equals the distance between the two points of tangency.

$\therefore$ H, H_1, and H_2 are all equal,

$$\text{then } \tan\theta = \frac{R-r}{H}$$

or the included angle $= 2\theta$

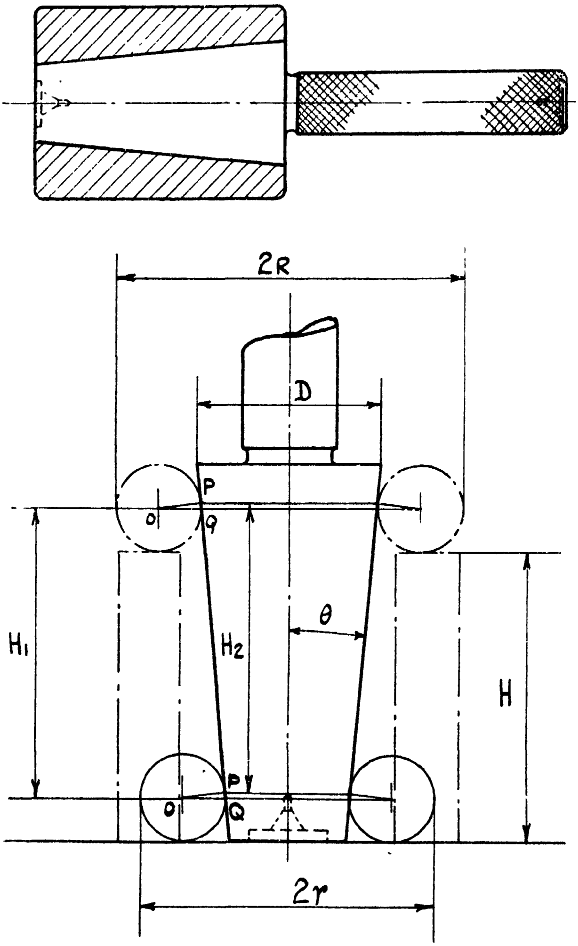


Fig. 6.—Taper plug and ring gauge

The Development of Form Tools

Various types of form tools were shown in the section on "Small Tools," but the actual development of these tools presents several problems for the tool designer which have not previously been discussed. When the cutting form is composed of straight lines, the amount for correction due to the rake of the tool can be calculated. A tool of this type is shown in Fig. 7, in which dimension X is to be calculated.

In Fig. 7,

$$OD = r$$
$$OA = R$$

angle $BOD = \theta$
angle $ADG = \delta$

Then, applying the sine rule in the triangle ODA

$$\sin OAD = \frac{OD \sin ODA}{OA}$$
$$= \frac{r \sin ODA}{R}$$

$$\therefore \quad \text{angle } AOD = \delta - \text{angle } OAD$$
$$= \delta - \sin^{-1}\left(\frac{r \sin ODA}{R}\right)$$

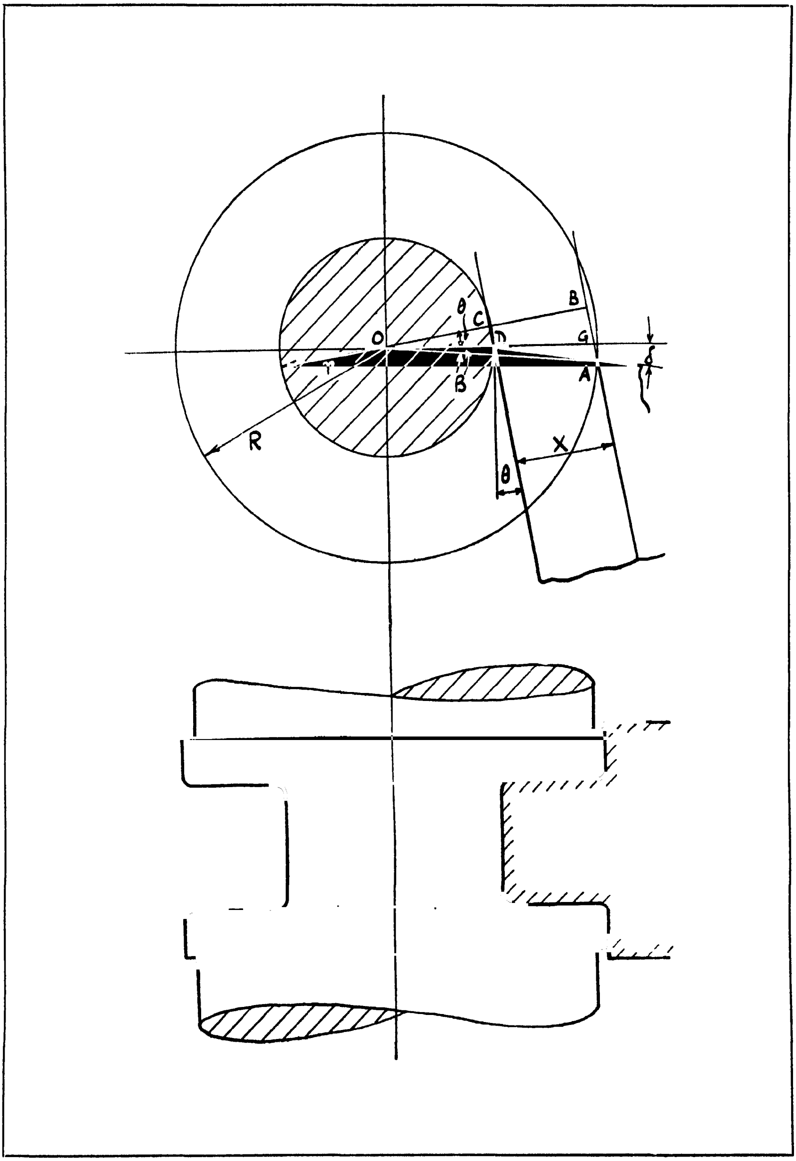


Fig. 7.—Form-tool correction

$$\text{and since } \sin ODA = \sin (180^\circ - ODA)$$

$$\text{angle } AOD = \delta - \sin^{-}\left(\frac{r - \sin \delta}{R}\right)$$

$$= \text{say } \beta$$

$$\text{angle } AOB = \theta + \beta$$

and in triangle AOB

$$OB = OA \cos (\theta + \beta)$$

$$= R \cos (\theta + \beta)$$

in triangle DOC

$$OC = OD \cos \theta = r \cos \theta$$

$$\text{Then } X \text{ required} = BC = OB - OC$$

$$\therefore \quad X = R \cos (\theta + \beta) - r \cos \theta$$

When curves occur on form tools, the following methods of obtaining the corrected form will be found satisfactory. Fig. 8 shows form tools as used on automatic and turret lathes. They are substantially covered by two types—circular-form tool and the dovetail-form tool. The circular-form tool is shown at A, the dovetail (so called from the shape of that portion of the tool which fits the holder) at B.

Circular-form Tool

The circular-form tool is used either on the front or back slide, is fixed to the holder by a bolt, and prevented from rotating when cutting by serrations formed on a boss on one side of the tool which fit in similar serrations on the toolholder. All cutting tools must be provided with front clearance, which may vary from 7° to 15°, according to the diameter of the work and the material to be cut. To provide this feature on a circular-form tool the top face is made flat and below the centre line of the tool, the cutting edge being raised to the height of the centre line of the work spindle as shown at C. The distance below the centre line of the tool to which the cutting edge is made is generally a standard peculiar to the machine tool on which it is to be used. It is not always essential to provide top rake, as this gives additional complications in the development of the tool. The profile of the tool, measured radially, is positioned at angle θ to the vertical. It is apparent that the form developed on the tool will not be reproduced on the work, due to the angle θ to which it is offered to the work. The angle α between the top face and the true cross-section modifies the shape as shown at D. The cross-section is circular and the angular section elliptical ; therefore this change of form must be taken into account when making form tools. Two methods for obtaining this modified form are explained. The first is by making a master gauge which has the corrections contained in the form, and the second is to generate a master-form tool with which to "shave" to size the production-form tool with corrections.

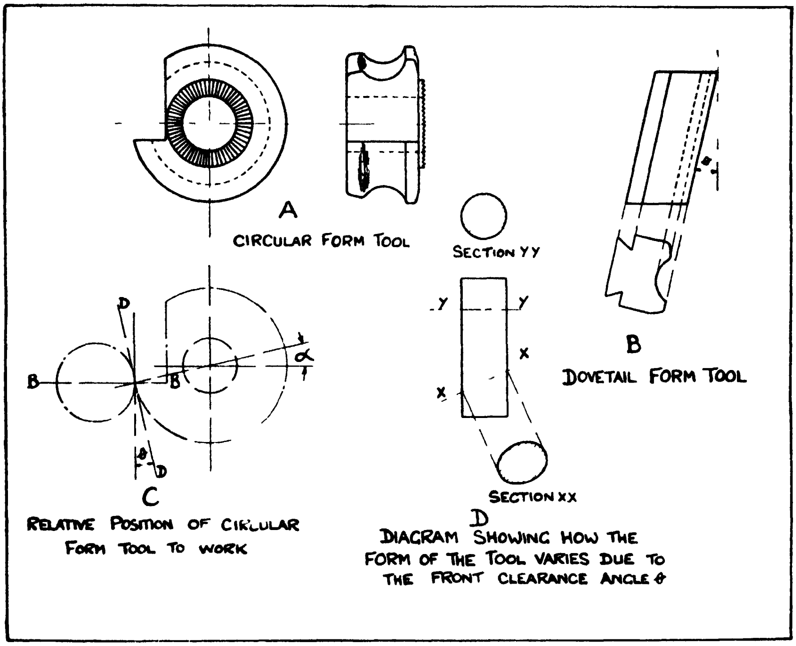


Fig. 8.—FORM TOOLS FOR AUTOMATICS

First Method (**Fig.** 9)

First make a plate gauge to the exact form of the work, as shown in Fig. 9 at *A*. Next turn a white metal blank (*B*), approximately the diameter of the finished tool, and cut the blank away an amount representing the chip clearance on the tool. Across this blank, through the line *FG*, shape the finished form, shutting out daylight to the master gauge, and, resetting the blank in the lathe, turn until a bare witness of the previous shaping remains along the line *HJ* (shown at *C*). Now machine the blank until one half only remains, and make a gauge *K* to the profile when the half-blank is lying on its flat surface. The gauge is then the master for a form tool not corrected for top rake. A tool made to this gauge, and the same diameter as the white metal blank, should now give perfect form, and although there is no top rake it can be used satisfactorily in the third or fourth position on a four-spindle automatic for a final scrape for correcting errors on the previous roughing tools.

Should it be required due to the nature of the material, usually on the free-cutting steels, that the final tool has top rake, then before

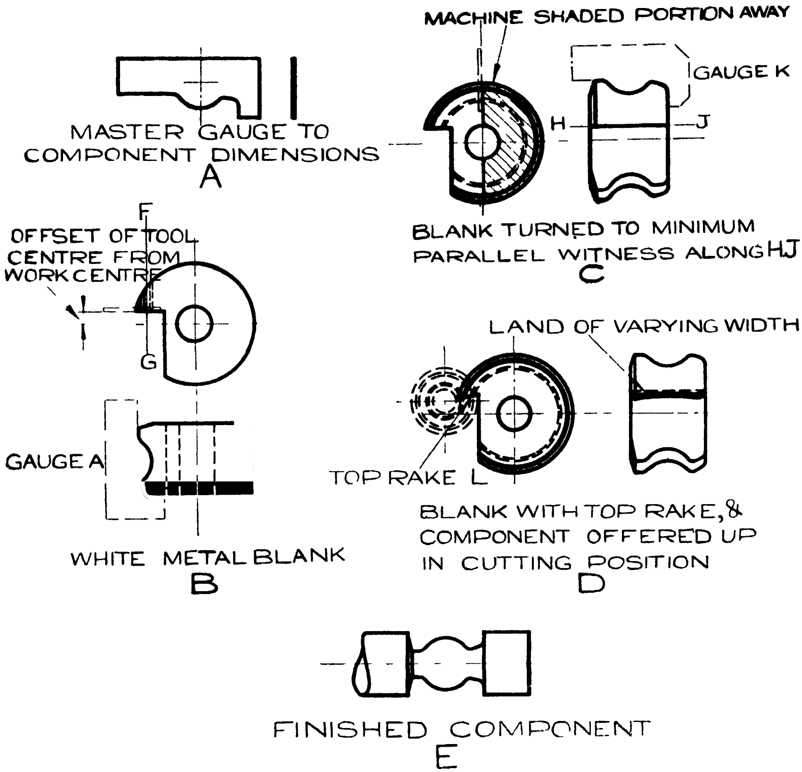


Fig. 9.—GENERATION OF CIRCULAR-FORM TOOLS (1ST METHOD)

machining the blank to obtain the half as previously described, cut the top rake (*L*) in the white metal blank.

Then offer up to it at the same setting as on the production machine (shown at *D*) a correct component *E*. This may be set up on a milling machine with the blank in a vice and the component mounted in a chuck or on the mandrel. Then allow the component to rotate, rubbing on the white metal blank until a " land " is produced throughout the length of the form. The blank can then be returned to a lathe and machined until a thin line of witness is left, to which a gauge is made in a manner similar to that required for the tool without top rake. Accurate spheres have been produced by tools generated in this way.

Second Method (Fig. 10)

First make a master-plate gauge as described in the previous method. Next a master tool (*A*) is made to the form of the master-plate gauge.

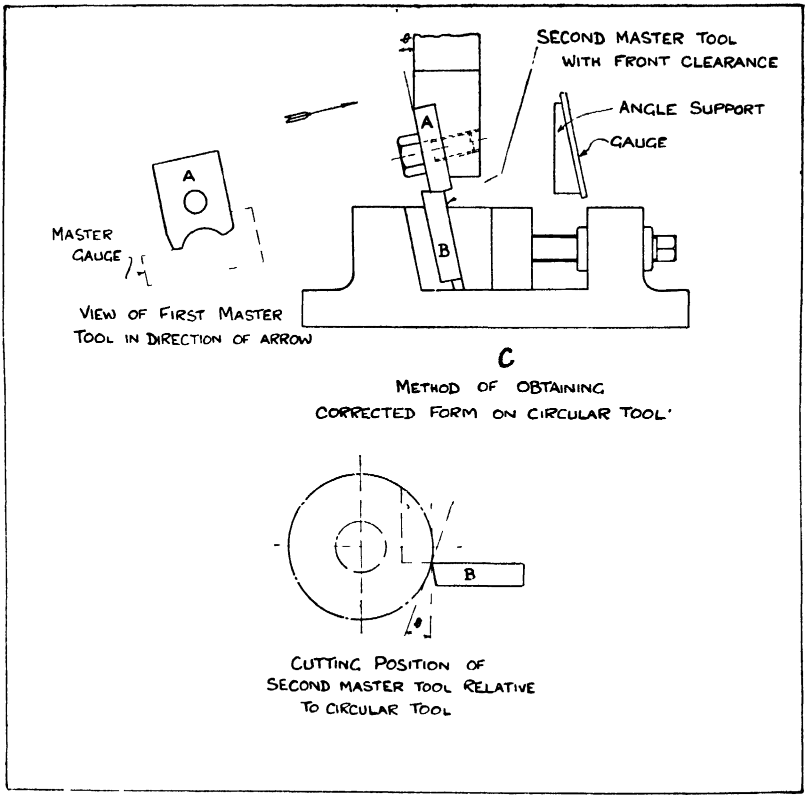


Fig. 10.—GENERATION OF CIRCULAR-FORM TOOLS (2ND METHOD)

Referring to diagram *C*, Fig. 10, it will be seen that in finishing tool *B* the tool *A* is fixed in a holder inclined at angle θ. *B* is also inclined at the same angle in the fixture. Very light cuts must be taken and the cutting tool lubricated with lard oil; ordinary cutting oil will not answer the purpose.

It will be noticed that the tool (*A*) has a negative rake as it is applied to *B*; thus it cannot cut in the usual manner, but only scrape. It is necessary, therefore, to shape *B* approximately to size by ordinary methods, leaving only a minimum to be removed by the scraping process. To facilitate gauging the roughing-out process, it will be found useful to employ an angle support to the gauge at the angle corresponding to the front clearance (see Fig. 10, *C*). The previously roughed-out circular-form tool is then finished with tool *B* set below centre to a pre-determined distance.

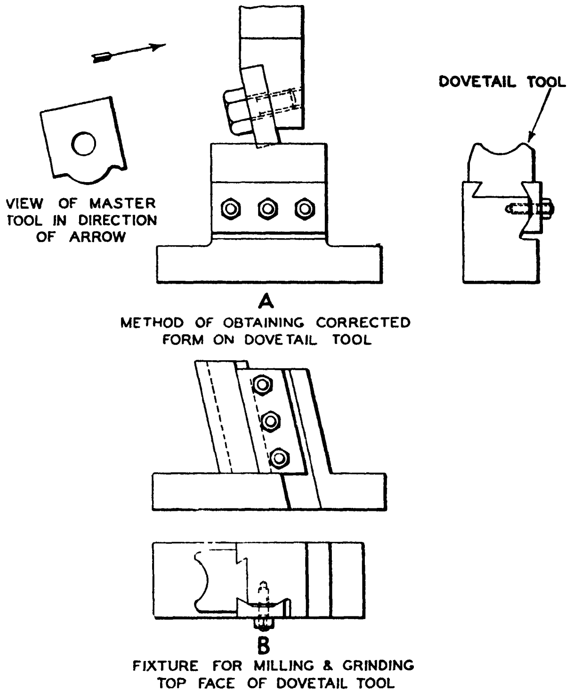


Fig. 11.—GENERATION OF DOVETAIL-FORM TOOLS

Due care must be taken when turning the circular tool, remembering that the forming tool *B* is below centre; consequently only light cuts may be taken because of the tendency for the work to mount on to the tool and so break the centre or bend the arbor. Although tool *B* must be used with care, it has been provided with the front clearance required to ensure that it will cut. After turning, the circular-form tool is gashed in the usual way and hardened off. Care must also be taken when sharpening the circular-form tool to ensure that the vertical distance from the cutting face to the centre of the tool is maintained

Dovetail-form Tool

The cutting conditions for the dovetail-form tool are essentially the same as for the circular type ; therefore the problem of correction for front clearance is substantially the same. Whereas the circular-form tool has front clearance because the cutting face is below the centre line of the tool, the dovetail type is wholly inclined in a suitable holder at the correct angle. The top face, which is ground at the same angle as the formed face, thus becomes radial to the centre of the work.

For the " Gauge " method, a suitable squared block of white metal is held in a shaping machine and a form shaped with an inclined tool. The form of the tool corresponds to that of the gauge, as previously mentioned. A corrected master gauge is now made to shut out light to

the form generated on the white metal. The gauge thus formed is used to control the form when making the dovetail tools.

Generating Method for Dovetail Tools (Fig. 11)

It will be seen from *A* that the method of making a dovetail tool by the generating process is fundamentally the same as that employed for the second master tool (Fig. 10, *C*), required for turning the circular-form tool, the only difference being that the first master tool is made to reversed contour of the production-form tool. As previously emphasised, the tool must be roughed out as near as possible before the scraping cut is applied. *B* shows a fixture for milling and subsequently grinding the top face after forming, the location being identical with the manner in which the tool is held whilst in operation. The dovetail tool illustrated has no top rake : if top rake is required, then the modified form can be developed by the same method as was recommended for circular-form tools.

Hardening of Form Tools

The success of any form tool, however accurately made, depends largely upon the care taken with the heat treatment—and this factor is even more important when dealing with form tools on which it is not considered necessary to grind the form after heat treatment. Whether the tool is ultimately ground on the form or not, care should be taken with the hardening, and the best methods employed.

The salt-bath method can be relied upon, and the equipment required comprises a pre-heating bath usually gas-fired ; a high-temperature bath generally of the immersed-element type ; a gas-fired quenching bath and secondary hardening bath. It is possible to use the quenching bath for the secondary hardening operation where small quantities only are treated at one time.

The tool to be hardened will first be dry-heated in a waste heat receptacle in the flue of the pre-heater to approximately 400° C., followed by pre-heating in the salt bath to a temperature of approximately 900° C. When the tool reaches bath temperature, which is readily observed by comparing the colour of the tool and the salt, it is transferred to the superheat immersed-element bath at a temperature of approximately 1,260° C. The time would vary according to mass, but for most tools the soaking time would be only two or three minutes. The work is then immediately transferred to the quenching bath, which should be in the region of 600° C., and left until the tool assumes the bath temperature, when it is removed and allowed to cool in still air to room temperature.

As soon as possible, the secondary hardening should be given to the tool, again in a salt bath at a temperature of approximately 580° C. for approximately 1 to 1½ hours.

The temperatures mentioned are typical for high-speed steel in the high tungsten or tungsten cobalt class but would vary a little according to maker's specification.

Chapter IX

THE UNDERLYING PRINCIPLES OF JIG AND FIXTURE DESIGN

WHILST the jig and tool designer is likely to meet a new problem on almost every component he handles, the underlying principles of tool design will be found to be similar in every branch of engineering, and it is advisable that these principles are understood and their values appreciated before work commences on actual designs.

Reduction of Idle Time

As a machine tool is only making profit whilst the tools are actually cutting metal, it is of interest to tour a works and, knowing the number of machines installed, put a mark on a piece of paper representing each machine actually cutting. Those who have not already done this will be astonished at the very low percentage of machines making chips. It should, therefore, be the aim of the tool designer to arrange that loading times are as short as possible, and where possible to arrange that loading can take place on one batch of components whilst another is being machined. The amount of money which can be spent towards the reduction of idle time is, of course, regulated by quantities, and the work of the designer is controlled in proportion.

Rigidity

Ensure that jigs and fixtures are rigid enough. The possibilities on some jobs are never realised through this fault. Milling fixtures require mass to damp out and absorb vibration.

Clearance between Jig and Component

Remember also to allow plenty of clearance between the jig and the component, because variations from the dimensions on the component drawing may be expected when they arrive into the works in quantities. Similarly, jig and fixture castings may differ from the drawing dimensions.

Cleaning

Quite a large proportion of the jigs which can be seen in any works are so many swarf traps, and it is surprising the amount of time which has to be wasted by operators in cleaning.

Locating Points

Make sure also that locating points are clearly defined and are not such that they are likely to hold swarf swept from adjacent positions.

Easy Loading into the Jig

Do not expect operators to be jugglers. Arrange that the component can be easily loaded into the jig. On heavy components give the operator an opportunity of sliding his component into the fixture. Do not put him in the position of having to " wangle " it in by hook or by crook, perhaps juggling with an air hoist at the same time. Consider the effort required and design to reduce it.

Sighting Faces

In the case of jigs where there are sighting faces against which parts of the component being machined must, for location purposes, be positioned, give the operator an opportunity of being able to see the faces easily without ricking his neck. Put the jig on trunnions.

Locating Pins

A useful wrinkle on subsequent operation jigs, particularly when machining heavy components, is to provide locating pins which disappear beneath the locating face and are raised into position after the component is roughly located in position, against adjustable screws or by other means.

Coolant to the Cutting Edges

Make sure also that adequate arrangements are made for the supply of coolant to the cutting edges, so that at the same time as the cutters are cooled the swarf is swept clear. This should be watched far more than it is, particularly on multi-drill jigs. It is no uncommon sight to see machine operators augmenting the flow of cutting compound when they could be more profitably occupied in preparing the next component. Another point often overlooked on milling fixtures is providing for the adequate control of the cutting compound. Arrange where possible, therefore, that the base forms a sump big enough to prevent the swarf and cutting compound flowing over the machine table and on to the floor.

Arrangement Drawing

If the arrangement drawing showing the component part in its relative position in an assembled unit is not available, the tool designer should obtain this information in order that the best location points for machining can be determined. This precaution is very necessary in many cases if satisfactory assembly is to result.

Lugs or Bosses

If the component, as designed, is difficult to hold, do not attempt to design a fixture the success of which appears doubtful or which indicates the slightest possibility of distorting or failing to grip the part. Consider the possibility of adding lugs or bosses for clamping purposes, even if they have to be subsequently removed.

Having determined the best positions from which location and on which clamping will take place, arrange with the foundry or stampers that no numbers or flash lines occur at these places.

When tooling castings, endeavour to avoid locating on faces formed by the core, but rather on parts formed by the pattern. Remember that cores are likely to shift during the foundry procedure.

Endeavour also to take locations from one half of any component produced in a split die, remembering that the opposite side of the die will not always close in precisely the same position, with the result that if the three locations, which are often required, are spread between the two sides of the component, varying results may occur.

Location for Accurate Work

When accuracy is required, do not attempt to locate from a hole or position previously machined on which a wide tolerance is permissible, but consider the advisability of having the tolerance tightened so that the required result on subsequent operations may be obtained.

Hardened Setting Block

Make arrangements, especially on milling fixtures, for hardened setting blocks and where possible for gauging faces also. This saves the operator, and sometimes the viewer, valuable time.

Clearance

Provide clearance on every jig, not only for the burrs thrown up in the previous operations, but also for those made by the operation being tooled.

Spanners

Make the jig as self-contained as possible. Avoid the use of loose spanners, but where this is unavoidable, use as few sizes as possible, so that the operator has not to search for the correct spanner.

Handles or Hooks

If parts of jigs or fixtures have to be moved or lifted by the operator or labourer, either during machining or at other times, provide the handles or hooks so necessary for this purpose.

Make Sure Component will enter Jig

Hundreds of jigs and fixtures are finished before it is found that the component will not enter the jig. This mistake can easily be made on the drawing-board, and the designer should always be watchful for this trap.

Clamping

Clamping should always be arranged directly above the points supporting the work. If this rule is disregarded, it will result in the springing of the work, causing it to be machined in a distorted position, resulting in inaccuracies after the work is removed from the jig, and, being released from clamping strain, resumes its original position.

Spring Locations

The number of locations on any rough component should never exceed three on any one plane. The component will " sit " on three points without rocking. Should it be necessary, however, for further supports to be provided, these should be spring loaded so that after the component is on the three fixed positions, others, where necessary, will automatically rise to touch the component through the medium of the springs. These sprung locations can then be locked in position.

Position of Clamps and Adjustments

Arrange that all clamps and adjustments are on that side of the fixture nearest to the operator whilst he is loading and unloading the component.

Design the clamping arrangements in such a way that they can be easily and quickly removed clear of the work, and avoid the necessity for lengthy unscrewing of nuts.

Particularly on milling fixtures, do not rely on the clamps to hold the work against the cut, but arrange fixed stops which will take the direct thrust of the cutters.

Arms or Abutments

Make your jigs and fixtures as convenient as possible for the operator, and where heavy components have to be accommodated arrange arms or abutments in such positions that one end can be roughly accommodated and the weight relieved whilst the operator gives the whole of his attention to the other end of the component.

Inserts

Care must be taken to avoid damaging faces which have been finished in previous operations. See that the clamping neither distorts the part nor spoils the finish. Brass, leather, or fibre inserts can be used on the clamping devices.

Component should be Ejected

Wherever possible, particularly on heavy components, arrange the jig so that, when unclamping, the component is either partially or completely ejected, so saving the operator the need for hammering or struggling with the piece. Air-operated fixtures lend themselves very well to this treatment.

Loose Parts

Where, for manufacturing purposes, it is necessary to have loose parts holding accurate bushings or locations, ensure that these, after being bolted, are dowelled in position and fitted against a shoulder, and be quite certain that the dowels are big enough in diameter to withstand a blow. In the event of the jig being knocked, a small dowel is easily partially sheared.

Clamping Fixture to the Table

Ensure that the arrangements for clamping the fixture to the table are such that it is bolted solid with the table and not sprung in any way.

Ensure that everything possible has been done to facilitate the manufacture of the jig and fixture. It may be that a machined ledge along the base of the casting may be very useful as a datum position for accurate machining and the viewing to follow, or a wall may be cast in some position for a like purpose, even if this has to be subsequently removed. Where holes are spaced around a circle or like shape, arrange that a hole be bored in the centre to take a standard plug from which they can be measured.

Safety of the Operator

Consider the safety of the operator and, especially on revolving fixtures, provide integral with the fixture, walls or guards to shroud abutments.

Foolproofing

This means designing a jig, fixture, or any tackle required for production in such a manner that it is impossible for an operator to insert either the work-piece or the cutting tools in any position other than the correct one.

This can usually be arranged by placing a pin or abutment in a position to clear the component when it is in its correct relative position, but fouling the component when the reverse is the case. Alternatively, it may be necessary to vary the sizes of pilot bushes in order that tools may not be applied through the wrong bushes in a jig. When the above pin or abutment cannot be applied, owing to the shape of the component being symmetrical, it often pays to make a small change, such as a difference in the size of one hole, or the addition of one hole.

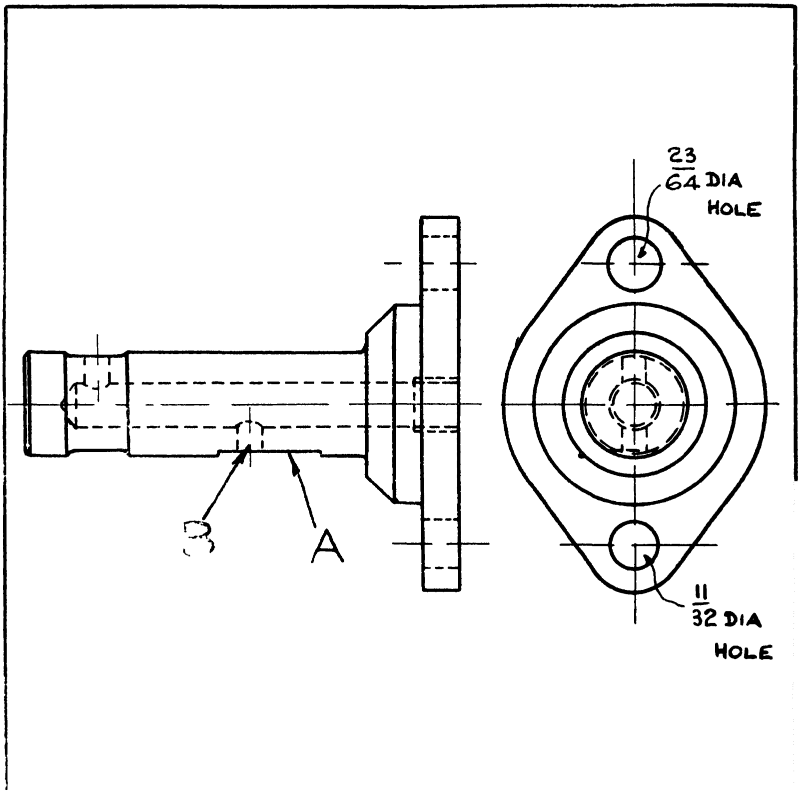


Fig. 1 —FOOLPROOFING THE MILLING OF A COMPONENT

On the component shown in Fig. 1 a flat has to be milled at *A*, and the fixture is arranged so that a number stand on the flange in line and an end mill of the correct width is passed along them using a horizontal milling machine. The flat has to be in correct relationship with the hole at *B*. Because of the component being originally symmetrical, it is possible to place the parts in the fixture so that the flat is machined on the opposite position to the hole *B*, with the result that pieces are scrapped. By changing the size of one of the holes in the flange from $\frac{11}{32}$ in. to $\frac{23}{64}$ in. and altering the locating pins in the fixture to suit, the parts cannot be placed the wrong way round in the fixture.

Scrap work has resulted in most production shops because arrangements for foolproofing have been forgotten by the jig and tool office

and yet contrary opinions exist regarding the making of devices foolproof, as instanced by the following paragraph, which is reproduced from a lecture given before a public body:

"In planning and scheming devices for production, they—tool designers—ought not to forget that in most cases the machines or devices had to be worked by human beings, and that those human beings had brains. In designing, they should always consider that the human brain could do more work than was perhaps imagined. Some machines and fixtures were made in such a way that they did not call for any interest on the part of the operators, who ought to be helped and encouraged to think, and so get real benefit from their minds."

If this policy was carried out in connection with the designing of jigs and fixtures, a large amount of scrap would undoubtedly result.

Although it will be found impossible on occasion to avoid contravening some of the foregoing principles, each and all are sound and should not be consistently ignored.

Chapter X

JIG AND FIXTURE DETAILS

NECESSITY and practical experience have resulted in many of the details embodied in jigs and fixtures following along definite lines. The examples given here are intended as a guide towards good practice. Designs of a fanciful nature have been omitted, and variations which will of necessity be required for peculiar purposes can be schemed using the examples as a basis.

Drill Bushes

These constitute that part of the drill jig through which the cutting tools—be they drills, core drills, reamers, or boring bars—are operated and located. When the accuracy or finish of the holes in the work is not important, and the machining may be done with a twist drill, then either of the bushes shown in Figs. 1 and 2 can be used. Fig. 1 is known as a plain drill bush and Fig. 2 as a flanged drill bush. Fig. 2 is often chosen because it may not be practicable to have sufficient thickness of metal in the jig plate to provide enough length to pilot the drill adequately. The flange of the drill bush can be extended to provide this length, thereby enabling the jig to be made of lighter construction.

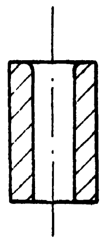


Fig. 1.—PLAIN BUSH

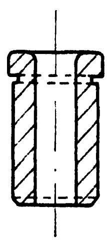
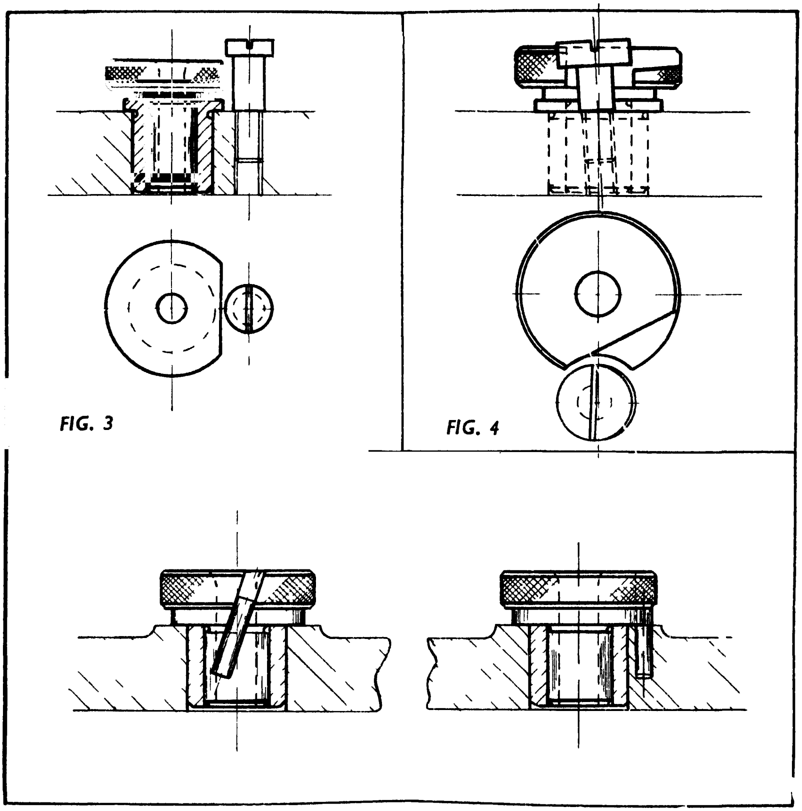


Fig. 2.—FLANGED BUSH

Should the bush plate be too thin to hold the bush adequately by a press fit, then the flange of the bush can be increased in diameter and countersunk head screws employed for the purpose of holding the bush down. These bushes should be made a good press fit into the jig. The flanged type of drill bush should be used wherever possible, in preference to the plain bush.

With the plain bush, particularly when the top of the jig is perhaps covered with swarf or cutting compound, there is no positive indication of its position, with the result that the drill is not properly centralised and there is a tendency for the point of the drill to run to the outside of the bush and so drill into or mark the jig. Because the flange bush stands proud, a better guide is provided for the operator. Where quantities are small, and the cost of the jig has to be kept to a minimum, the plain bush may be used, it being cheaper to manufacture.

Where greater accuracy and finish is required, it is necessary that the holes are drilled undersize and further tools used to obtain the required



Figs. 3–5.—Slip bushes

result, or when it has been decided that holes requiring tapping can best be machined whilst the component is still in the jig, then slip bushes will be required. These slip bushes will be of a size in the bore to accommodate subsequent tools, except when tapping, when they are removed.

As these will have to be removed or interchanged between the various operations, they cannot be a press fit and must be so designed that they can be easily removed, and in the majority of cases prevented from revolving or being pushed up or out of the fixture by the swarf resulting from the cutting operation.

Types of Slip Bushing

Figs. 3, 4, and 5 are examples of this type of bushing. These examples are the simplest and most effective types, although more

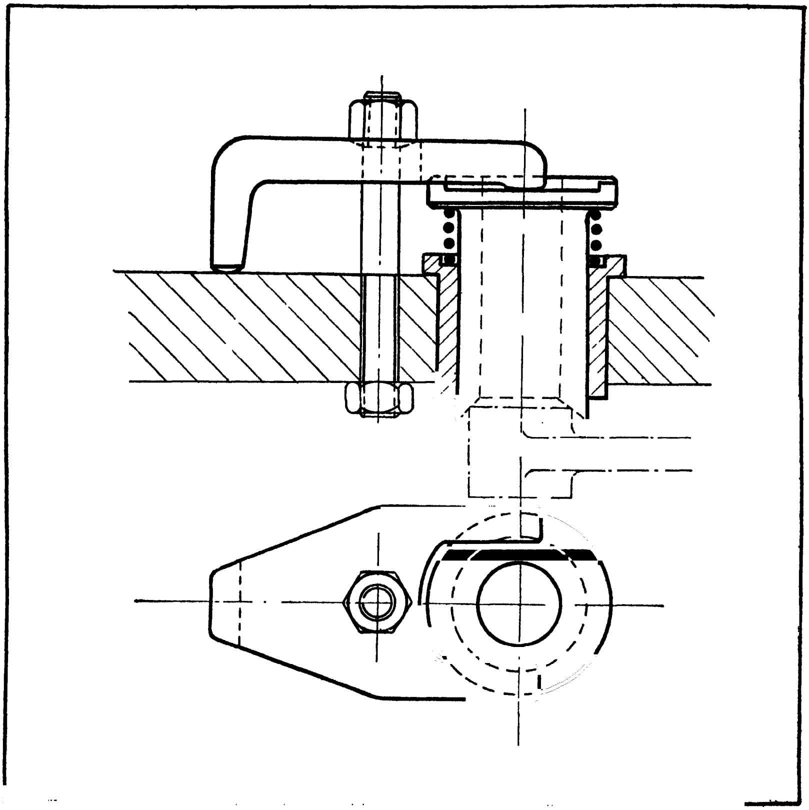


Fig. 6.—Drill bush used for locating and clamping

complicated arrangements are used. Due to the presence of swarf and the hard usage to which drill bushes are subjected, complications are to be avoided.

Fig. 3 is the type perhaps most generally in use. The flat machined on the flange of the slip bushing allows the head of the bush to drop below the head of the stop pin. A slight turn of the bushing places the bush head under the screw head, so preventing it from lifting.

Fig. 4 is very similar ; it is a little more costly to manufacture and has an advantage in that the bush becomes more or less locked by the incline machined on the bush head locking underneath the screw. It is, however, not so quickly removed from the jig.

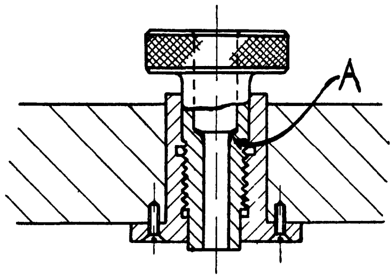


Fig. 7.—Drill bush used for clamping

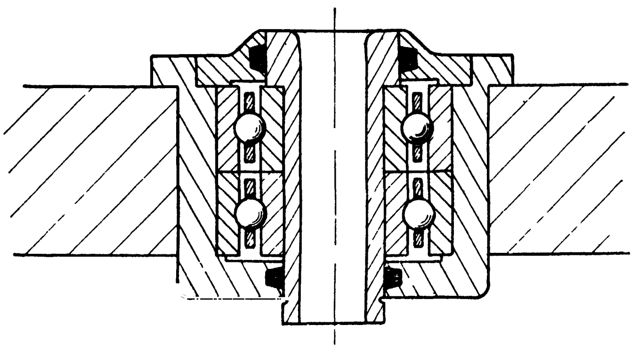


Fig. 8.—Bush for piloting high-speed boring bars

Fig. 5 is a useful and simple type, but it will be found that the stop pin has to be frequently replaced.

The type of bush shown in Fig. 6 is often employed and is used for the dual purpose of both clamping and locating the work. It is chiefly used when locating from a boss, through which a hole has to be drilled. The hole through the bush is chamfered at the bottom, the top of the boss locating in the chamfer, as shown in the diagram. In order that the work may be easily withdrawn from the jig, a spring is used to raise the bush. The clamp is retained in position by the two legs which straddle a tenon machined on the top of the bush. The fixed bush within which the locating bush is placed should be long enough to ensure that the latter is kept in alignment.

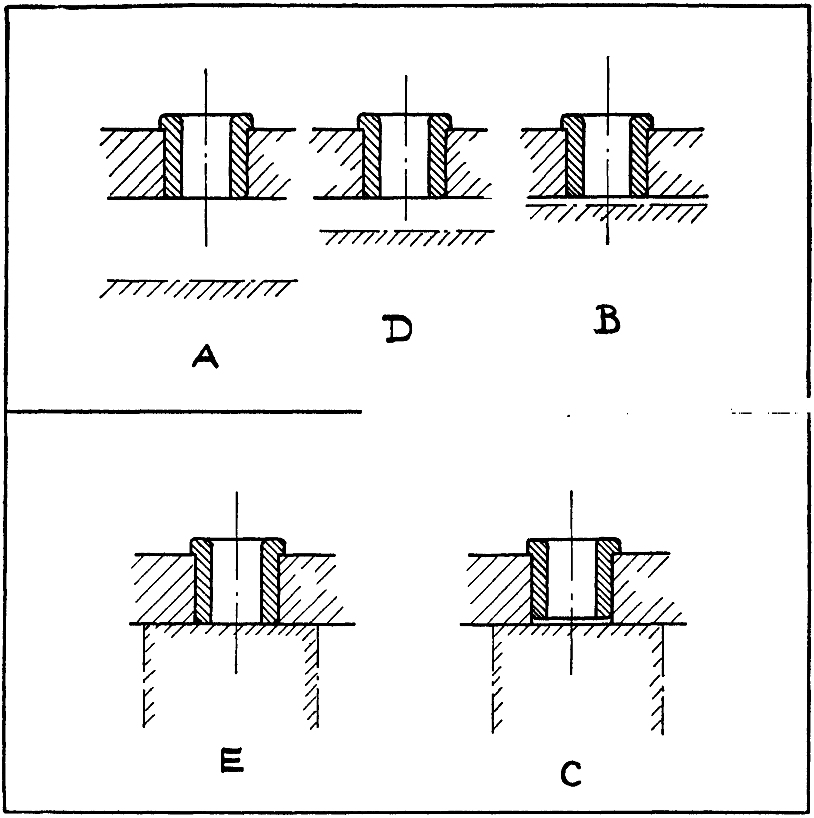


Fig. 9.—Good and bad practice in mounting bushes

Fig. 7 is also a type of bush used for clamping the work, and this is done by screwing the bush downwards. The bush is kept in alignment by being piloted in the fixed bush both above and below the screwed portion. The top of the bush is relieved so that too long a bearing on the drill is avoided.

The type of bush sometimes used for high-speed work is shown in Fig. 8 and chiefly employed for the piloting of the high-speed boring bars. Ball races are made a light-drive fit in the outer casing or fixed bushing, whilst the bush is similarly fitted in the bore of the bearings. A cover is placed on the top to prevent cutting compound or chips entering the bearings. A recess is cut in this cover and also in the bottom

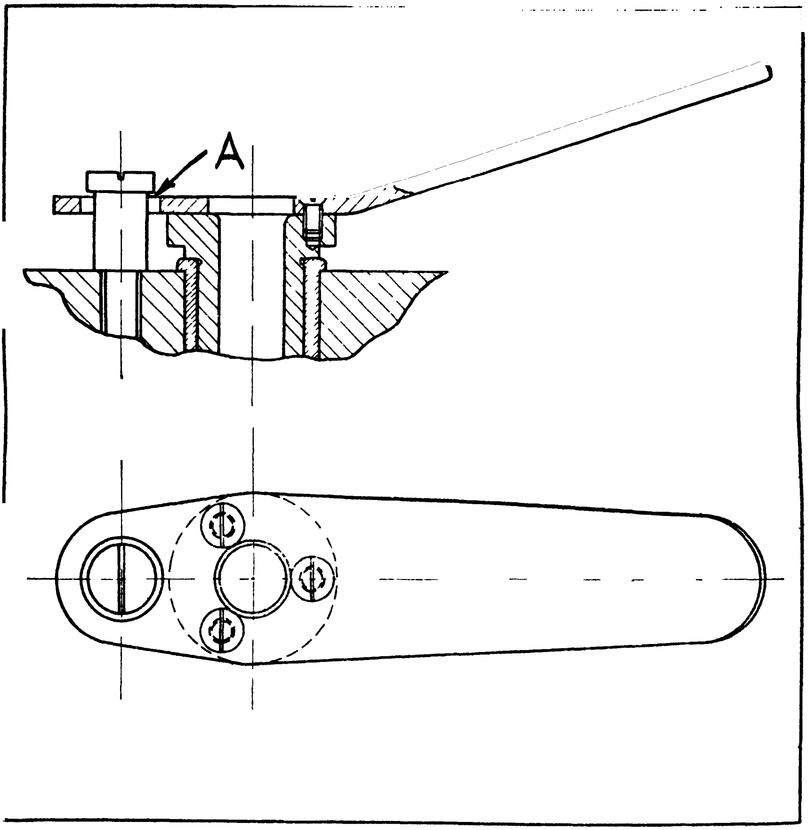


Fig. 10.—HANDLE FOR REMOVING SLIP BUSHES

of the bush, and these are packed with felt to prevent the exit of the grease with which the ball races are lubricated.

The bores of drill bushes should be radiused at the top to prevent sharp corners destroying the cutting edge of the drill. When extra long bushes are unavoidable, the amount of bearing surface in the bore should be relieved by counterboring and radiusing the shoulder as at *A*, Fig. 7. Chamfering is not so satisfactory because of the tendency for the sides of the taper to deflect the drill, a condition difficult to detect.

Examples of good and bad practice are shown in Fig. 9. At *A* the end of the bush is too far from the work ; at *B* it is too close and is likely to be crowded with swarf, whilst at *C* the gap between the end of the

bush and the work forms a swarf trap likely to cause drill breakage. *D* and *E* show examples of correct practice.

Drill bushes too short will not be adequate to hold the drill in alignment. They should be made in length about two and a half times the diameter of the drill.

When of necessity slip bushes have to be so placed in the jig that an operator is likely to lose time when removing them, handles can be screwed to the top flange. Fig. 10 shows a handle serving a dual purpose. The hole at *A* is large enough to drop over the stop pin, and by a small movement of the handle the bush is prevented from turning or being pushed out of the jig. When bushes are heavy, double-ended handles can be used, providing that there is sufficient clearance available.

Sizes of Bushes for Tapping Drills

The following table gives, in a compact form, core diameters and sizes of tapping drills, and includes the sizes in everyday use by tool designers of Standard Whitworth, British Standard Fine, British Standard Pipe, and British Association Threads. Whilst the sizes given for tapping drills are accepted standards in everyday use, the designer will sometimes find it necessary to vary these to suit certain materials. Similarly, when machine tapping, it will often be necessary to drill a slightly larger hole than when hand tapping. The bore of the bush should be slightly larger than the drill size for the drill to be a good running fit in the bush.

TAPPING DRILLS FOR SCREW THREADS

Size	*Standard Whitworth*		*British Standard Fine*		*British Standard Pipe*			*British Association*		
	Core Dia.	*Tap Drill*	*Core Dia.*	*Tap Drill*	*Outside Dia.*	*Core Dia.*	*Tap Drill*	*No.*	*Core Dia.*	*Tap Drill*
In.	*In.*		*In.*	*In.*	*In.*	*In.*	*In.*		*In.*	
1/8	·0929	No. 40			·383	·337	11/32	0	·1890	No. 10
3/16	·1341	9/64 in.						1	·1661	No. 17
1/4	·1860	No. 9	·2007	13/64	·518	·451	15/32	2	·1468	No. 24
5/16	·2414	1/4 in.	·2543	G				4	·1106	No. 32
3/8	·2950	5/16 in.	·3110	P	·656	·589	19/32	6	·0852	No. 43
7/16	·3460	23/64 in.	·3664	3/8				8	·0663	No. 50
1/2	·3933	13/32 in.	·4200	27/64	·825	·734	3/4	10	·0504	No. 54
5/8	·5086	17/32 in.	·5335	35/64						
3/4	·6219	41/64 in.	·6433	21/32	1·041	·950	31/32			
7/8	·7327	3/4 in.	7586	25/32						
1	·8399	55/64 in.	·8719	57/64	1·309	1·193	1 13/64			

Jig Feet

Jigs which have to be moved about on a machine table must be provided with feet of one kind or another. The accumulation of swarf

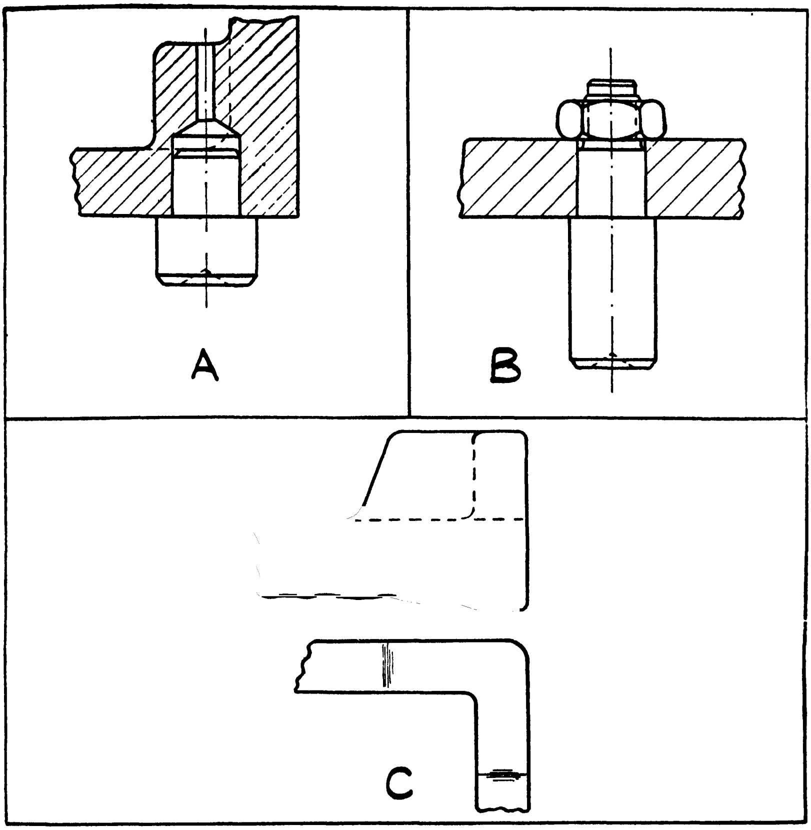


Fig. 11.—JIG FEET

renders it impracticable to stand jigs on a flat base, because so much time would have to be spent and care taken by the operator to ensure that the table was clean for accurate results to ensue.

Jigs should therefore stand on small areas, but not so small that they can become wedged or fall in holes or slots in the machine table.

Fig. 11 shows examples of the various types of feet in general use. The button type at *A* is pressed in, and wherever possible the hole in which the smaller diameter fits should break through at the back to provide access for punching it out, should the need arise.

On flat plate jigs feet must be long enough to clear the component, and when it is necessary to turn the jig over for loading purposes, the

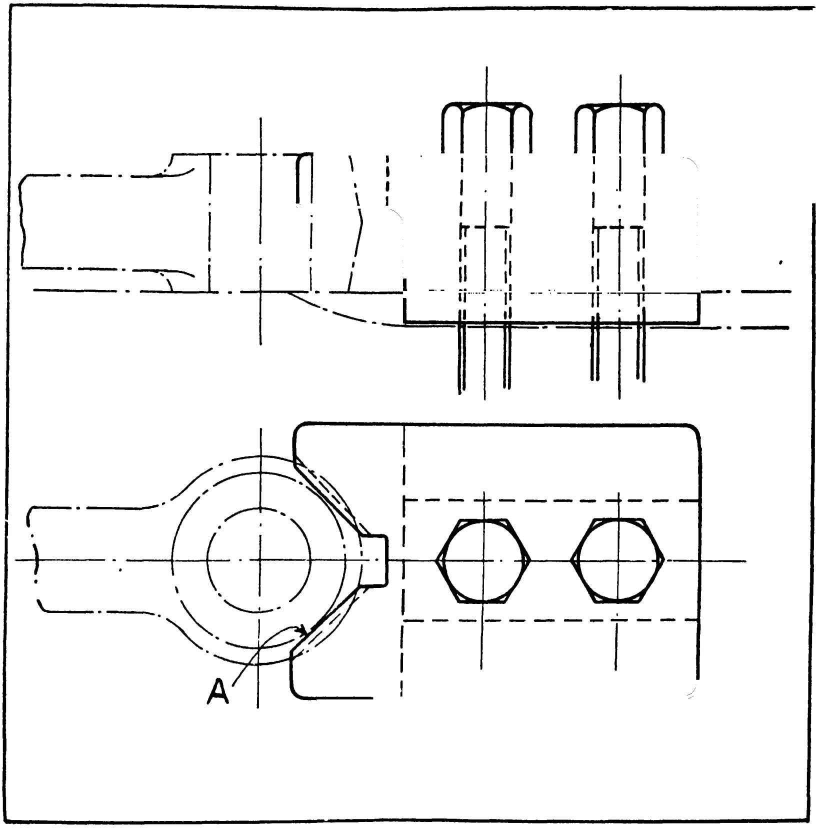


Fig. 12.—Fixed vee location

foot should be extended through the plate and locked in position by a nut as shown at *B*.

When a casting forms the body of a jig, then the feet can be made integral and extended along two sides as a small right angle, as shown at *C*. Such feet should not stand too " proud " because of the danger of breaking, but should not be less than ¼ in. from the jig body. On large jigs where the section of material is adequate, up to ¾ in. is satisfactory.

Vee Locations

Whilst the well-known tool-makers' type of vee block has, for location purposes, to be incorporated in many jigs and fixtures, it is the intention

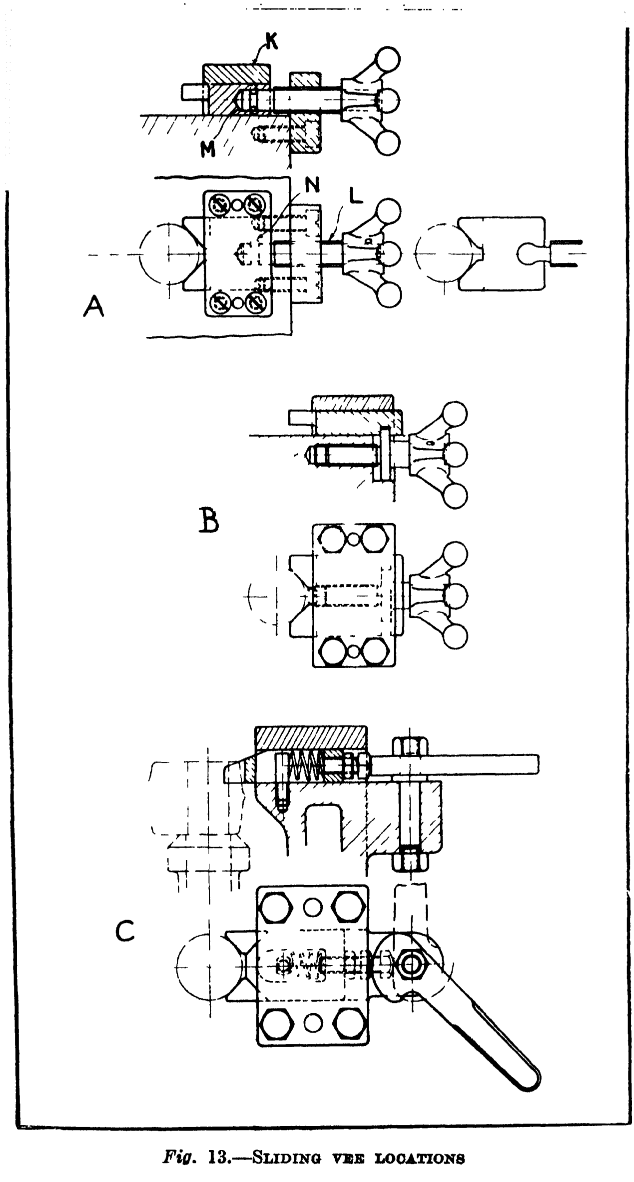


Fig. 13.—SLIDING VEE LOCATIONS

under the above heading to describe variations only of this type of location.

When the boss to be located is long enough to allow the vee to be raised above the facing on the jig, as in Fig. 12, which shows a fixed vee, an advantage is obtained in so far that small particles of swarf are less likely to accumulate at the base of the vee—yet should this happen, they can be readily removed. It is advisable that the vee blocks are tongued—not only does this facilitate the assembly of the jig, but the possibility of the part being moved by accident is eliminated. When it is desirable that the vee block tends to hold the component downwards, then the locating faces should be angled, as at *A*.

Sliding vee locations, alternatives of which are shown at *A*, *B*, and *C*, Fig. 13, are necessary when one part of the component is already located in another part of the jig or fixture and the boss to be received in the sliding vee is free, until locked, to swing into the desired position. In the arrangement shown at *A* the vee is covered by the guide plate *K*, swarf being thereby kept out.

The vee is moved to and from its objective by the screw *L*, the forward thrust being taken on the end of the screw *M* and in the opposite direction by the pin *N* which passes through a groove turned around the plain portion at the end of the screw. The screw in this instance is turned by a hand nut.

An alternative method of designing a sliding vee location is shown at *B*. This is very similar in construction to the one previously described, except that instead of the thrust being taken on the end of the screw, both forward and backward movements are made through a flange integral with the screw which contacts in a slot cut underneath the vee block. To hold the screw in alignment a counterbore is arranged into which the outside diameter of the flange fits.

A more rapidly actuated arrangement of a similar location and one which is preferable when room is available for its accommodation is that shown at *C*. In this instance the forward, or clamping, motion is obtained through the cam lever and the reverse motion by a spring fitted inside the vee block. The reaction of the spring is taken against a pin located in the centre of the slot cut in the vee. Adjustment between the vee block and the cam face is made by the screw and lock-nut fitted to the end of the vee piece. The cam form should be designed to give rapid initial movement with a slow lock. This arrangement may be a little more costly, but should be considered wherever practicable.

Jacks and Supporting Pins

In jig and fixture design it is not always possible to clamp the work directly to either the base or one of the walls of the fixture. Perhaps the component is not machined at those places where it is most convenient

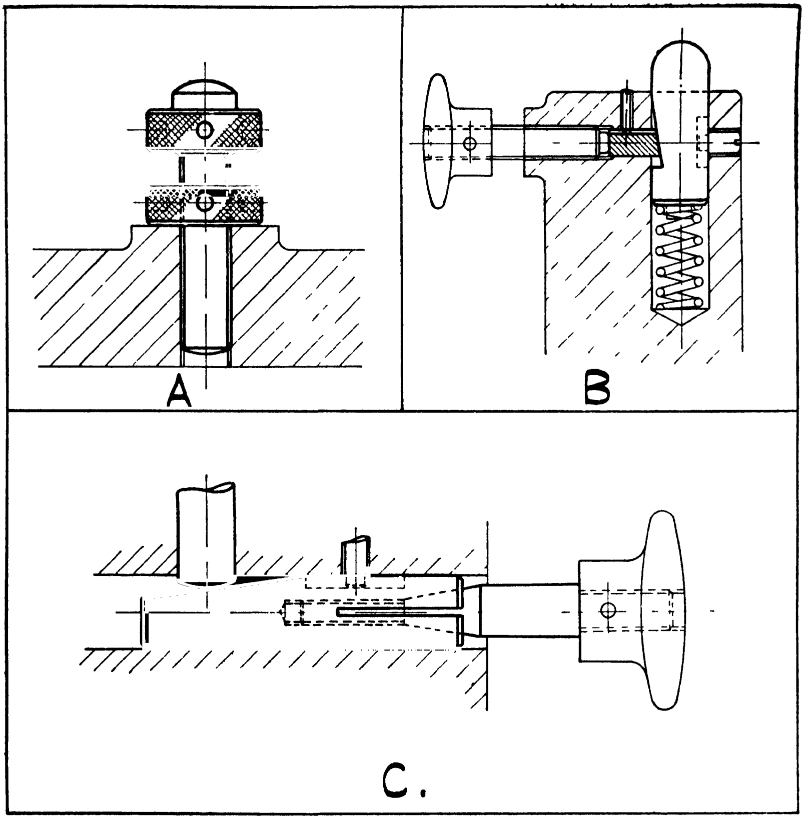


Fig. 14.—JACKS AND SUPPORTING PINS

to effect the clamping. In such instances, jacks or pins are raised to support the work beneath the clamps.

Fig. 14(A) shows a very simple and cheaply made type, and is comprised of a knurled head screw and a knurled nut. The screw is raised by hand until it meets the component, and is then fixed in position by screwing down the locknut. Tommy holes are drilled in each part for the convenience of the operator.

Fig. 14(B) shows a type of jack pin which positions itself automatically and is raised into position by a compression spring situated beneath it. Upon assuming its correct relative position, the pin is prevented from dropping by turning the hand nut, which forces a pin, on which an angle

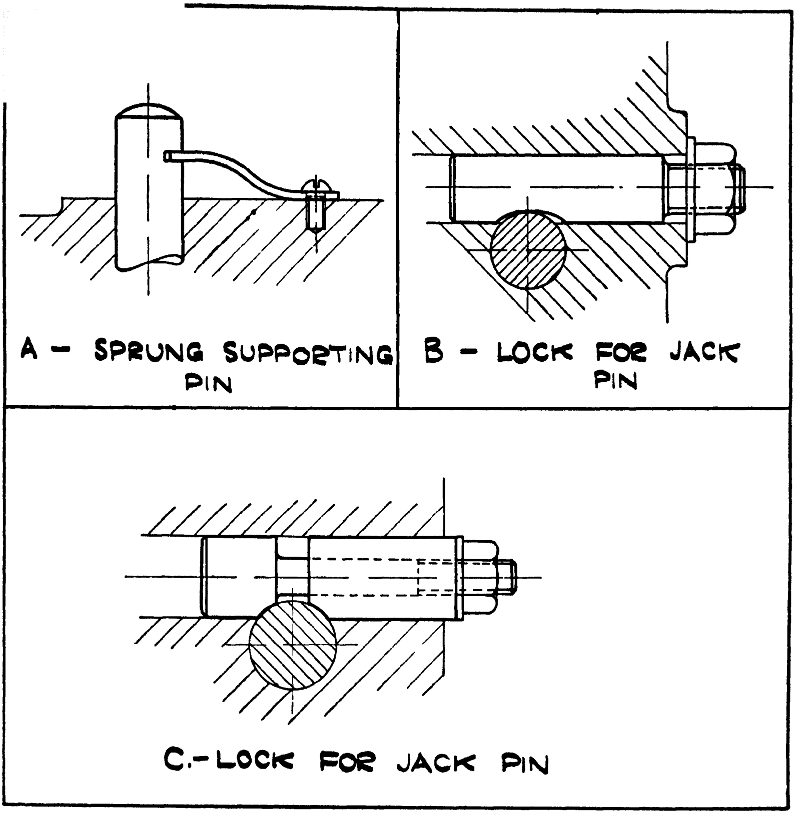


Fig. 15.—JACKS AND SUPPORTING PINS

is machined, against a flat of the same angle provided on the jack pin itself. To prevent the locking pin and the jack pin from getting out of position the one with the other, a keyway, into which a small dowel peg is screwed, is milled in each of these parts. This type of jack is the most generally used and will be found to be very effective.

Fig. 14 (C) shows a further common type, but, in this instance, is not automatic. The setting of the jack pin is done by pushing the hand nut, and consequently the taper pin attached to it, towards the jack pin ; the jack pin riding up the taper provided is raised until it touches the work. It is then prevented from dropping by a turn of the hand nut, which opens the split end of the taper pin, thus locking it in

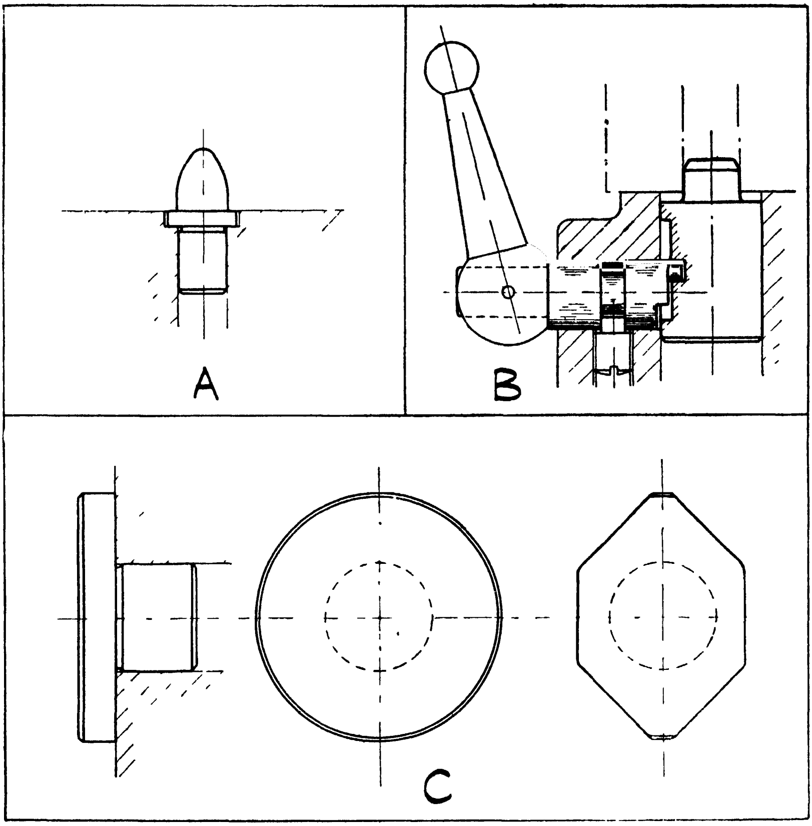


Fig. 16.—LOCATING PINS

position. This taper pin is prevented from turning by a dowel peg in a keyway.

Fig. 15 (A) shows another method of automatically raising a pin to meet the surface of the work, but its application will be found to be restricted, owing to the limited range of the leaf spring employed.

Fig. 15 (B) and (C) show methods employed for locking jack pins in position. (C) is the sounder of the two in design, but a little more costly to manufacture. When the nut is tightened, the head of the bolt and the collar are forced together, thereby clamping the pin by the radii formed on either part and which correspond to the diameter of the jack pin.

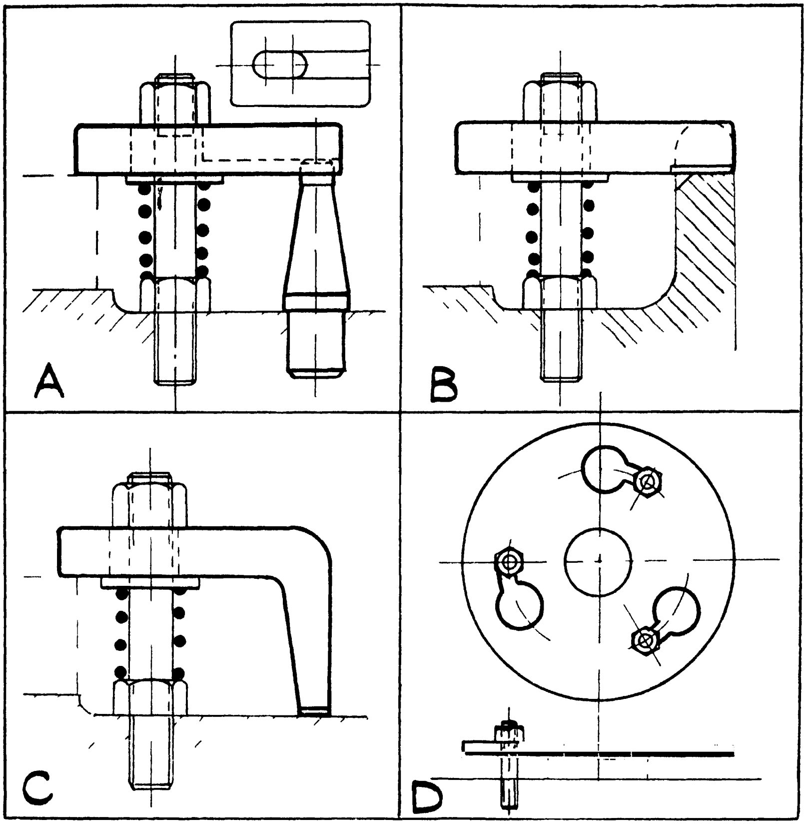


Fig 17 —Clamps

Locating Pins

It is often essential that components are located from previously machined holes, and Fig. 16 shows the types of locating pins most generally used.

Fig. 16 *A* shows the most-used type of shouldered locating pin. The shoulder is provided to prevent the pin being pushed into the fixture by the work. The pin is pointed in order that the operator may more readily apply the work to the correct position.

When component parts are of a heavy nature and it is only possible to slide them into the jig or fixture, it is of advantage that disappearing pins be fitted. Such an example is shown in *B*. By movement of the hand lever it is possible to lower the locating pin into the fixture to faci-

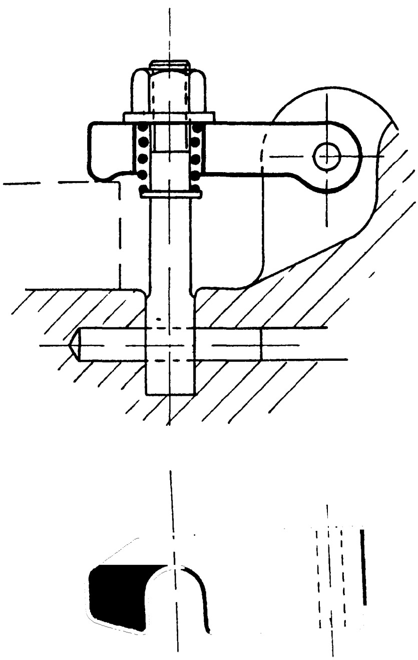


Fig. 18.—Hinged clamp and bolt

litate the loading and unloading of the work and then to raise it into position as required. This is effected by means of an eccentric turned on the operating pin, which fits into a slot in the locating pin.

When it is required that location takes place from two previously drilled holes, it is usual for one of the pins to be made flatted—as shown in *C*. The location of the one pin is thereby reduced to two small portions only. These are left on opposite sides of the pin and square with a line running through the centres of the two locating pins. Should there be any slight deviation from the true centres between the holes in the component which fits over the locating pins, the flatted pin will allow the necessary compensation to make possible the easier loading into the fixture.

Clamps

Very few jigs and fixtures can be designed without some clamping device being incorporated for the purpose of holding the work in the correct relative position in the fixture, or, as is sometimes the case, clamping the jig to the work. The latter case is often used on large components where a few holes are required adjacent to previously machined faces and the component is capable of standing on its own base. It is of primary importance, therefore, to study the correct method of clamping and also to be familiar with methods of clamping and types of clamps. The study of the varying types of clamps shown will save the designer much searching to invent a type of clamp suitable to any particular requirement. Whilst the range shown is fairly comprehensive, it should not be thought that the examples limit the possibility in this direction : the ingenuity of the designer can still be profitably exercised.

Fig. 17 *A*, *B*, and *C* show examples of the more generally used types of clamps, the only difference between them being the arrangements made to form the heel on the opposite side of the stud from the work. In *A* the heel is a loose piece turned from mild steel. In *B* the body of the

fixture is cast to form an integral heel, and in *C* the clamp is forged, carrying its own heel. In *B* and *C* the foot of the clamp on the heel is radiused to form a three-point contact, two of them being on the work and the other on the opposite end of the clamp. *A* does not need this radius because the top of the heel pin, being small in area, serves the same purpose. It will be noticed that the stud passes through an elongated slot. This is provided so that when a nut is slacked off the clamp may be drawn back clear of the work in order that the component may be more easily loaded into the fixture. The compression springs beneath the clamps are provided to hold the clamp up against the nut to free the operator from the necessity of picking up the clamp and manœuvring it over the work.

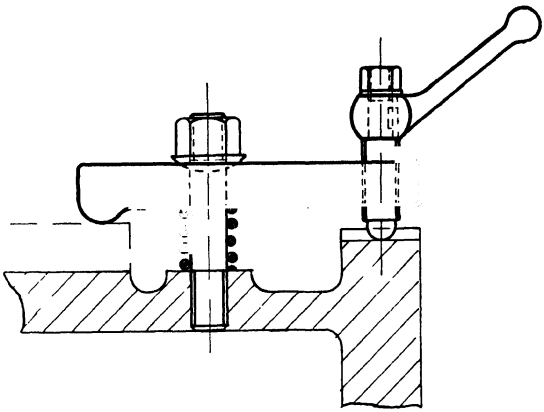


Fig. 19.—Hand-operated clamp

Fig. 17 *D* is another much-used type of clamp, particularly when circular components have to be accommodated. The clamp in this instance is a circular steel plate, the nuts being tightened over elongated slots. It will be readily appreciated that when the nuts are released the plate can be turned a few degrees, until the holes, which are drilled larger than the nuts, are in such a position that the plate may be lifted clear. The nuts will remain on the studs and so save the necessity for the

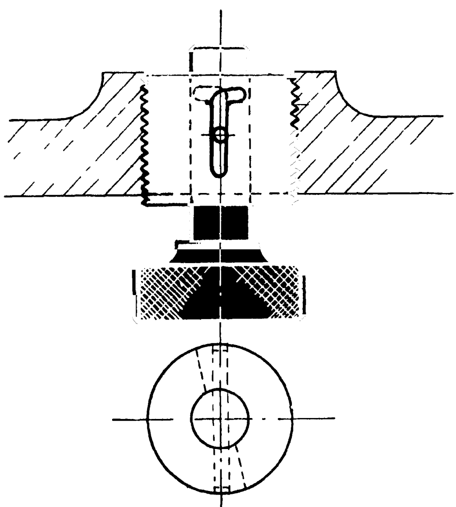


Fig 20.—Rapid type of hand-operated clamp

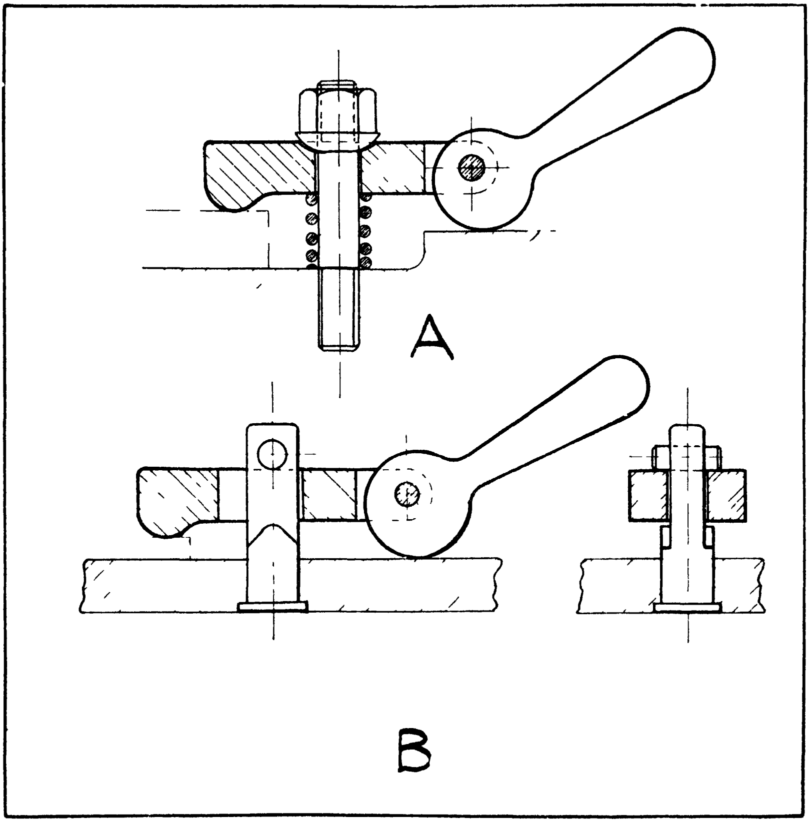


Fig. 21.—CAM-OPERATED CLAMPS

large amount of spannering which would be required if each nut had to be unscrewed from the studs to remove the plate.

Fig. 18 is a combination of hinged clamp and hinged bolt. This type of clamp is often required when it is necessary to move both the clamp and the bolt completely out of the way for the loading of components. In this instance a coil spring is used to hold the washer under the nut to save the operator time. The jig casting is so formed as to provide lugs or positions for the hinge pins.

Fig. 19 is a variation of the first three clamps described arranged to obviate the need for spannering and is useful where heavy clamping is not required. The spherical washer is fitted under the centre stud to

enable the clamp to float to three-point contact between the work and the heel. Spherical washers beneath clamping nuts can be employed on many occasions with advantage, but it is not recommended as a general practice, the spherical washer being more costly than the ordinary plain washer. The clamping lever is keyed to the screw, which in this case forms the heel pin. The point of the screw "rides" in a slot to prevent the clamp getting out of position.

Fig. 20 is an example of a rapid type of clamp—useful where heavy clamping is not required. This consists of a centre pin which abuts on the work. Through this pin and protruding on either side is another pin of smaller diameter. A screwed plug is fitted into the fixture casting and on either side of the plug is cut an elongated L-shaped slot along which the small diameter pin is free to move in two directions. The clamping is done by pushing the clamping pin to the bottom of the elongated slot, turning it into the foot of the L, when additional turning moves the nut towards the work and the clamping is effected. To release the clamping pin, a slight turn to the left will release the nut and the pin can be rapidly drawn down the elongated slot and so clear of the work.

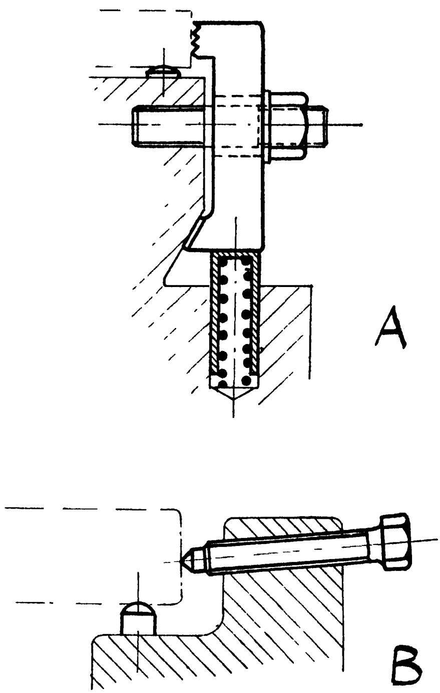


Fig. 22.—"EDGE" CLAMPS

Fig. 21 shows two arrangements of cam-actuated clamps. These two types may be employed to advantage for holding components on which there is no great variation in position of the face to be clamped. The clamping is rapid and no searching for spanners is required, the tightening and releasing being done by a downward and upward movement respectively on the clamping lever. The amount of eccentricity should be carefully plotted in order that the cam rise is not too rapid and so that sufficient mechanical advantage may be obtained by gradual cam increment.

In *B* the reaction of the clamp is taken on the pin through the centre

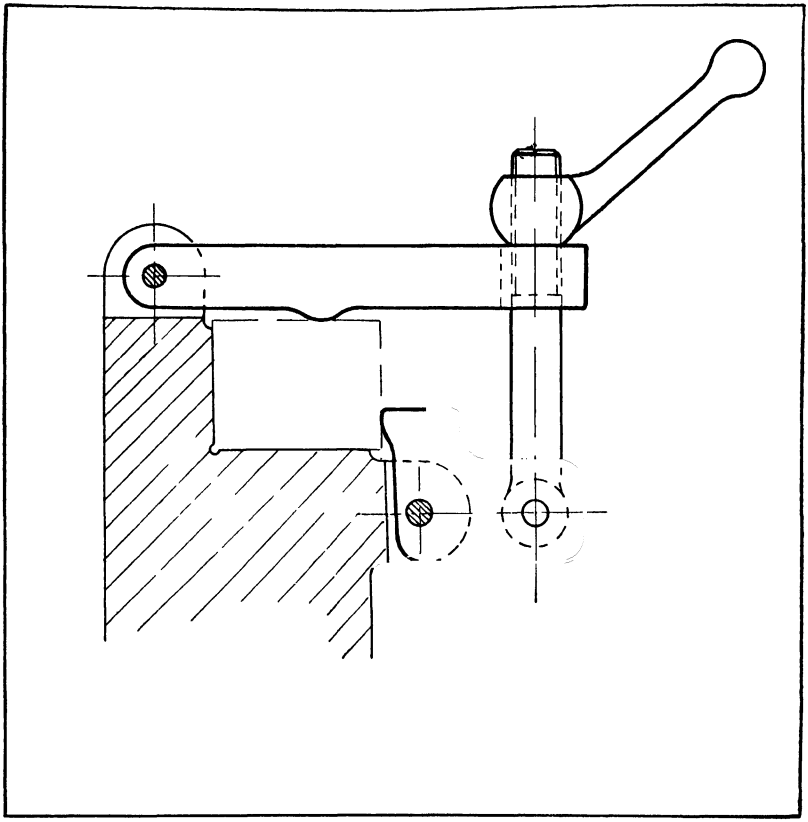


Fig. 23.—TWO-WAY CLAMP

pillar and the clamp is prevented from falling by the vee form which is shown on the pin and beneath the clamp. An elongated slot is provided so that the clamp may be pulled free from the work for loading purposes.

Fig. 22 shows two examples of clamps which hold by gripping the work on its edges, and are particularly useful when no part of the clamping mechanism must stand above the faces being machined.

In *A* the heel of the clamp is shown on an angle, so that when the nut is tightened the tendency is not only to clamp the work sideways but pull it down also on to its locating face or stop. It is usual in this instance to serrate the clamp's face. The support plunger seen beneath the clamp

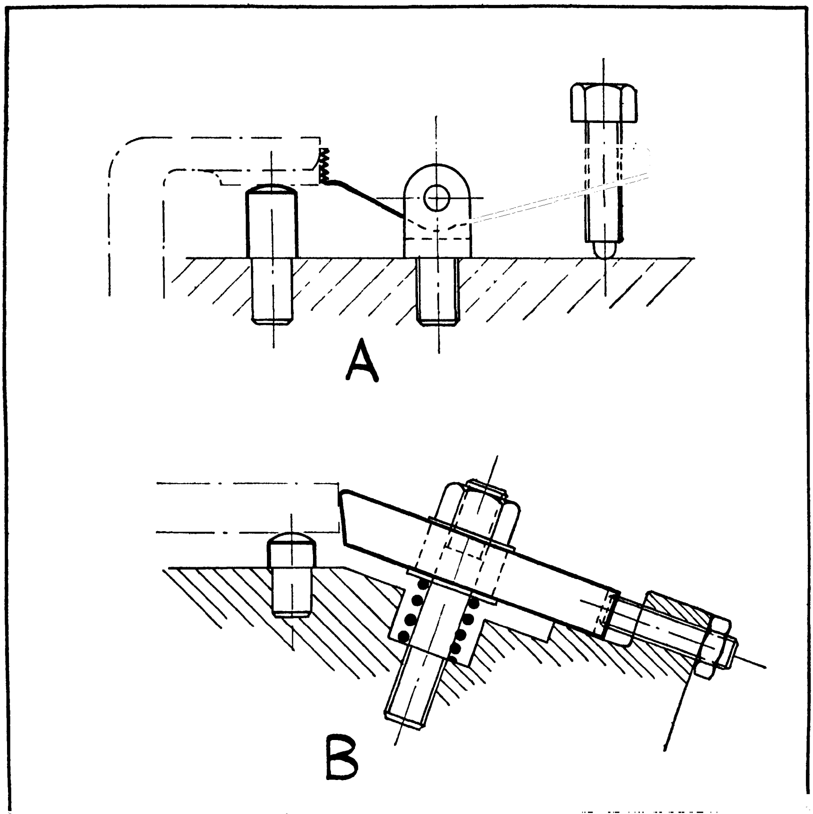


Fig. 24.—" Edge " clamps

is arranged to take the weight of the clamp and hold it in its relatively correct position until the load is applied. The heel of this clamp is also radiused.

The type of clamp shown in *B* has much to recommend it. It is cheap, simple in construction, and positive. It can only be used, of course, against rough or irregular faces on which the mark left by the hardened point of the screw is not objected to.

Fig. 23 is a further example of rapid clamping in two directions from one screw. In laying out clamping of this description, care should be taken to ensure that the length of the levers is such that approximately equal pressure is applied by each clamp at its clamping position. The

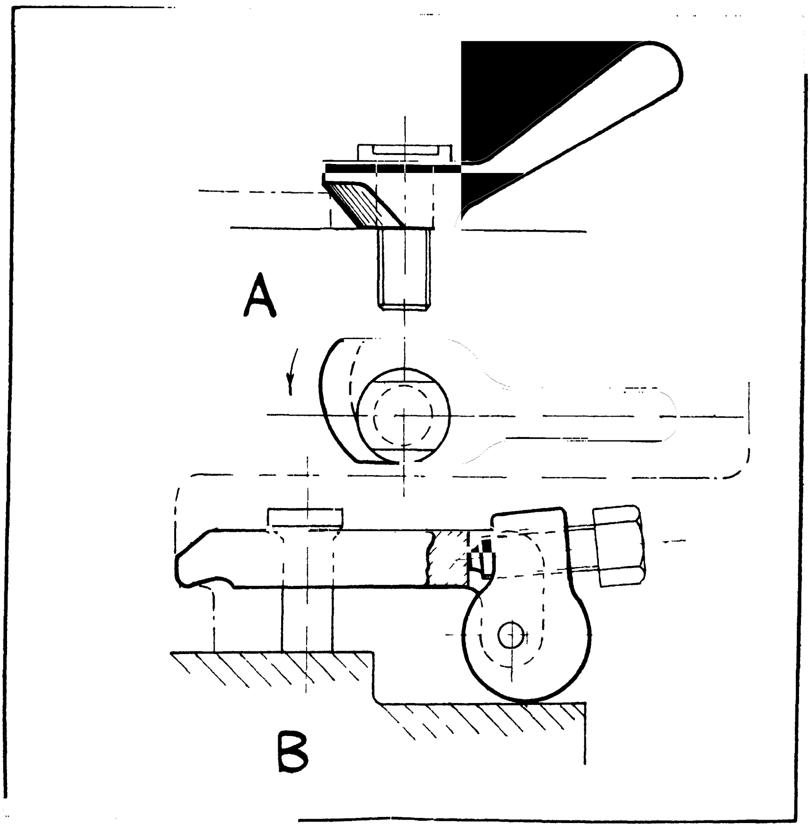


Fig. 25.—CAM-OPERATED CLAMPS

top clamp is slotted at the end in order that the whole of its clamping mechanism can be swung clear of the work.

Fig. 24, *A* and *B*, are two further examples of sideways clamping and should only be employed when the face to be clamped assumes practically the same relative position on each component after it is placed in the fixture. It will be noted that neither of these clamps will accommodate any great variation in length.

Fig. 25 *A* is another example of cam-actuated clamping. The end face of the boss on the clamp is angled for the purpose of holding the work down, the cam face of the clamp pressing the work sideways against its location. This is a frequently used type.

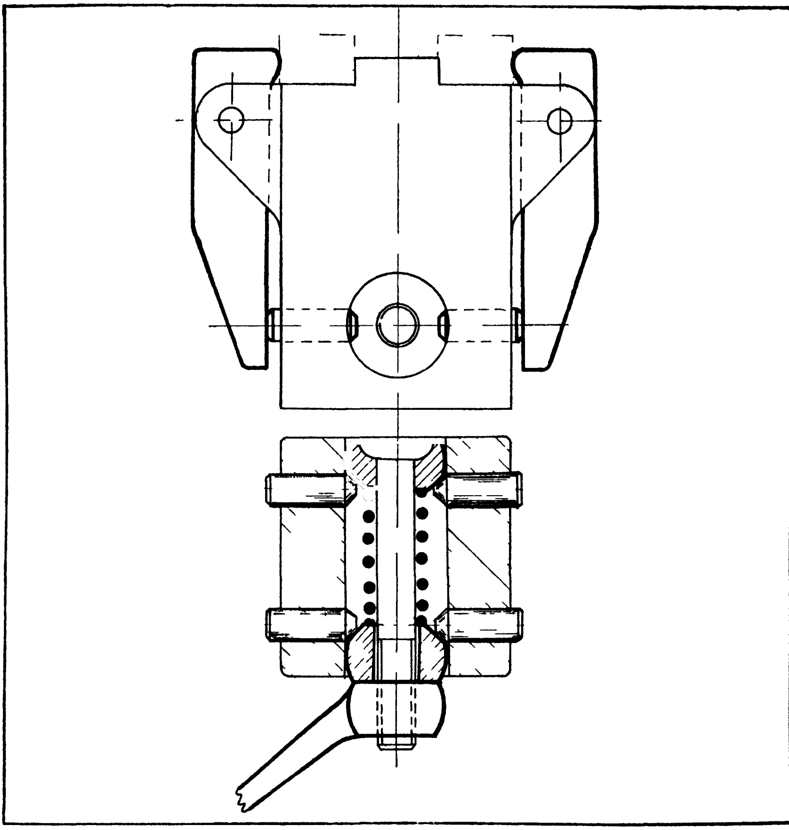


Fig 26 —SYNCHRONISED MULTIPLE CLAMPING

Fig. 25 *B* is a useful design when the space for clamping is limited, or clamping has to take place beneath an overhanging portion of the component. Although a cam is employed in this instance, the load is applied by turning the screw against the bottom of the slot cut to form the forked end of the clamp.

Fig. 26 represents a synchronised clamping arrangement whereby four clamps are located on the work simultaneously by turning one clamping lever. The turning of this lever shortens the distance between the two hardened cones, which, in turn, push outward the pins beneath each clamp. The mechanical advantage obtained by the difference in the lengths of the levers from the fulcrum pin on which the clamps

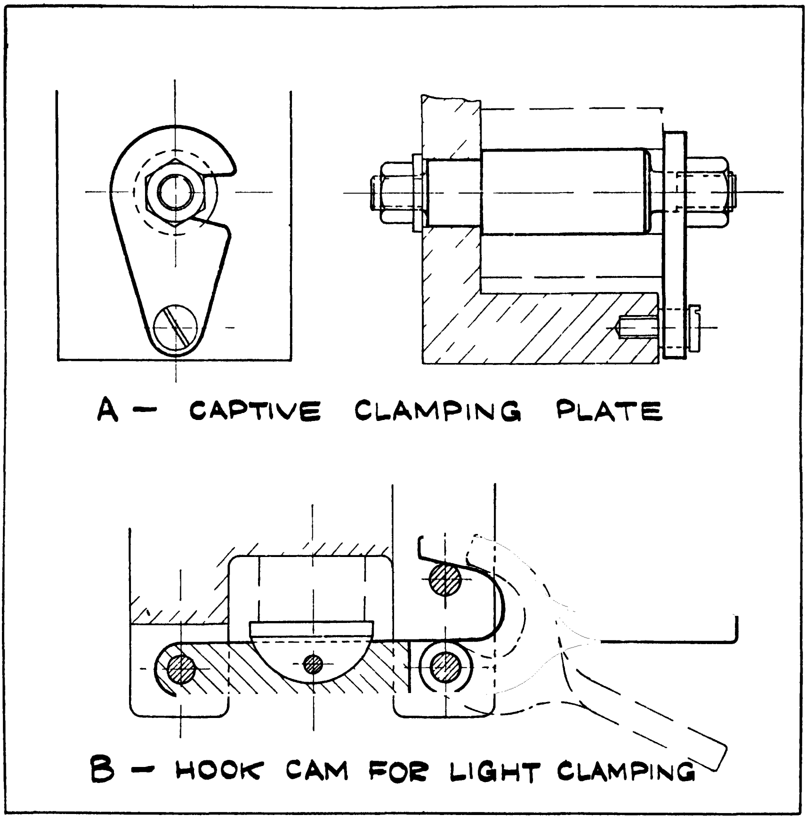


Fig. 27.—Two useful clamping devices

operate is sufficient to apply considerable pressure. This type of clamping is a useful time-saver, but, owing to the complication of wearing parts, is not recommended where very heavy clamping is required.

Fig. 27 *A* is a very much-used type of clamping, particularly on drill jigs where drilling has to take place from a previously bored hole. The component is pushed over a locating pin, and the clamping plate is swung into position under the nut. By this method the clamping plate cannot be lost, as it remains fast to the fixture. This is a simple and effective method of clamping, and is to be preferred against the slotted washer, which has often to be replaced at frequent intervals.

The device shown in Fig. 27 *B* is useful for rapid clamping and is

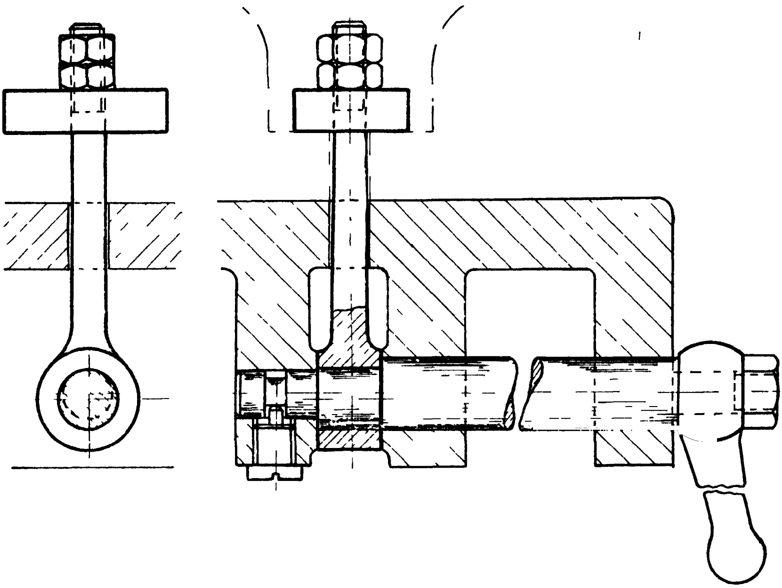


Fig. 28.—Eccentric-operated clamp

applied when machining time is short. It is only suitable for light clamping and where components are approximately the same length. The clamping lever is hinged on the clamping bar which, in its turn, is hinged on to the fixture. Along the clamping bar is fitted a floating pad which holds the work, and the clamping lever is then forced against a pin or other abutment fitted to the fixture. This type of clamping is a little more costly to manufacture and maintain, but when quantities are sufficient to warrant its use, the cost is quickly recovered over the time saved in handling spanners and nuts.

Fig. 28 is a particularly useful, very effective, and much-used type of clamping, and is most usefully applied when clamping has to be done in positions awkward for the operator to reach—such as the bolting down in the centre of large castings. The eye-bolt used for pulling the clamp down is fitted over an eccentric machined on a bar. The bar is extended through and underneath the fixture to some outside position within easy reach of the operator, and the clamping is done by the turning of a lever which remains fixed in position. The recess turned in the end of the eccentric bar, in which a dowel screw is shown, forms a means of preventing the bar from moving longitudinally in the fixture.

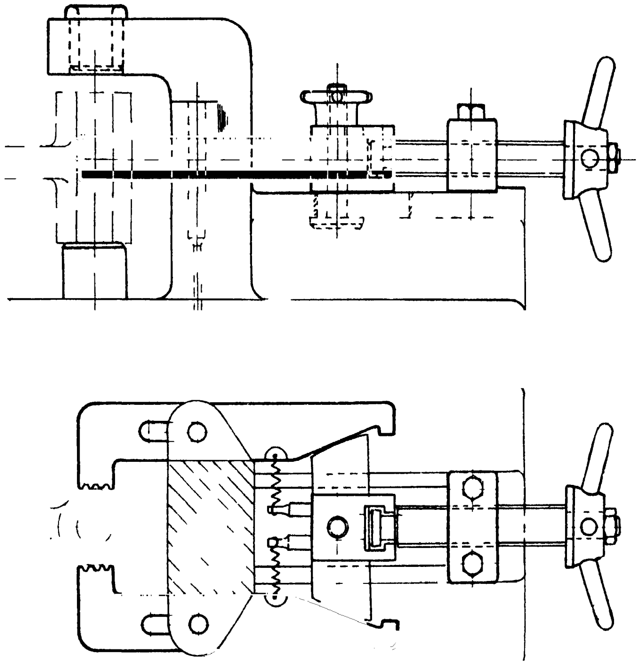


Fig. 29.—DIFFERENTIAL CLAMPING

Differential Clamp

Conditions necessitating the design shown in Fig. 29 are :

(1) Loading from the side, which requires clamps to be withdrawn.

(2) Clamps to adjust themselves to the errors in the stamping, with the rigidity to absorb the heavy cutting strain on the large boss, which is comparatively lightly attached to the remainder of the component.

The action of clamping is as follows :

The right-hand clockwise rotation of the star wheel thrusts the wedge bar forward, which, in turn, advances to side clamps until the end of the travel of the slot is reached. A further rotation of the star wheel then causes the jaws to close, and the side first to meet the component is held up until the second jaw makes contact. It will be realised that, at this point, both clamps are fully differentiated.

The further action of screwing causes the clamps to hold the component with necessary pressure, and the whole is then secured from any floating by clamping the locking handwheel.

For withdrawing the component the reverse action takes place.

Chapter XI

DRILL JIGS

WHEN considering the design of drill jigs, the designer will be able to apply many of the principles enumerated previously under "Underlying Principles of Jig and Fixture Design." It is not proposed to reiterate these principles, but it is expected that the designer will recognise the application of many of them in the various examples of drill-jig design which follow. In these examples the dot-and-dash lines indicate the components.

In the section headed "The Jig and Tool Department" will be found examples of the economics of tooling, and this factor must be considered before deciding on a type of jig suitable for the quality and quantity of the workpieces. It should be borne in mind that widely varying types of jigs could be made for a given component, each of which would be satisfactory for producing the piece, but some of which would cost many times more than the others, and be outside the bounds of practical production economics.

The first consideration, therefore, in the design of a drill jig must be that of cost in relation to the number of components for which it will be used. This question of cost should be considered in conjunction with the class of labour which will be using the jig. Boy or girl labour will require a certain standard of easy and foolproof operation below which it is not desirable to drop, whilst a semi-skilled or skilled operator will perform the same operation satisfactorily with a simple type of jig.

Marking-off Templates

It is proposed to commence the examples of drill-jig practice with a type that is only one stage removed from the marking-off table. This is shown in Fig. 1 and is not strictly a drill jig, but consists of a simple template which is used for marking off the holes to be drilled. The component and template are either rested on a block or held in a vice while centre pops are made through the countersunk holes (*A*) in the template. The template is then removed and the component set up for drilling to the centre pops.

It will be clear that this method is not conducive to great accuracy, but it is effective on certain parts as a means of saving the cost of marking off each component where the cost of a jig is unwarranted. Fig. 2 shows a similar type of template which goes one step further by providing hand-operated clamp screws (*A*) to hold the template and the component together whilst using the centre punch.

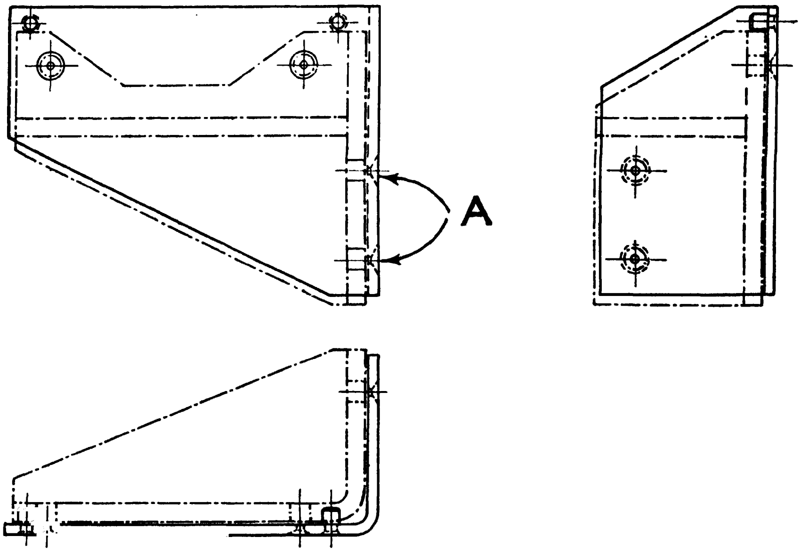


Fig. 1.—Marking-off template

Simple Built-up Jigs

Fig. 3 shows the next step forward in jig design, a type of jig in frequent use. This is built up of standard material and provides hand clamping of the component, together with a fair measure of accuracy of location. In connection with the location, an important principle of design is exemplified. The holes in this component are dimensioned on the drawing from the outer face (A) of the angle section ; therefore this face of the component is clamped against the jig.

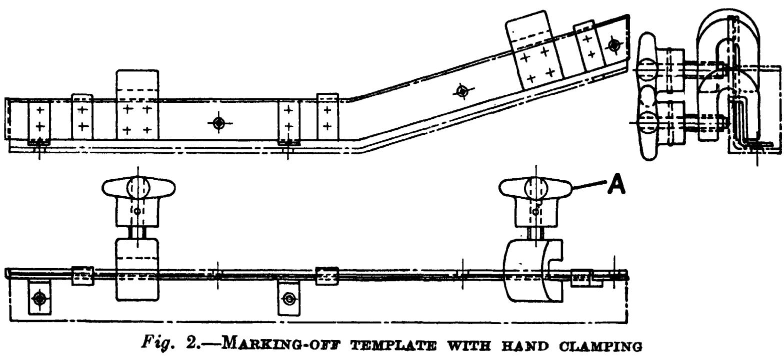


Fig. 2.—Marking-off template with hand clamping

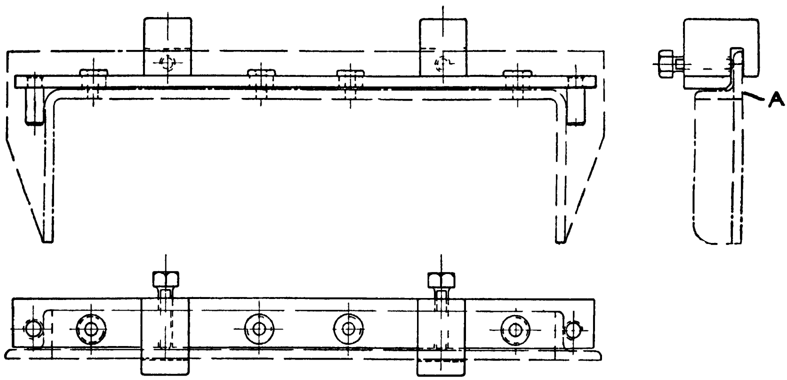


Fig. 3.—SIMPLE BUILT-UP JIG

In other words, the faces of a component from which holes are dimensioned should be—if the piece is properly dimensioned—the faces from which the jig locations are taken.

A similar pattern of jig is shown in Fig. 4, this jig being built up of standard material by welding. The component is clamped by means of hook bolts (*A*), which are backed up by means of heel blocks (*B*). Heel blocks are always necessary when using hook bolts, both for the purpose of maintaining even clamping and also to prevent excessive bending stresses being set up in the bolts, these stresses being sufficient on occasion to break the bolts. The welds in this jig are shown marked *X*.

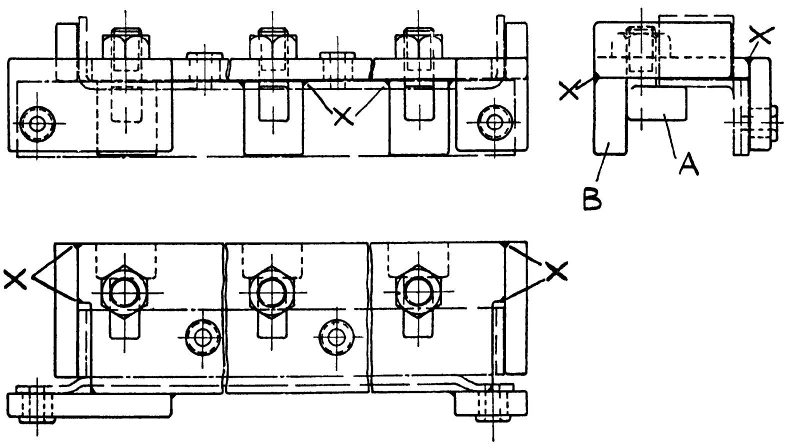


Fig. 4.—SIMPLE WELDED JIG

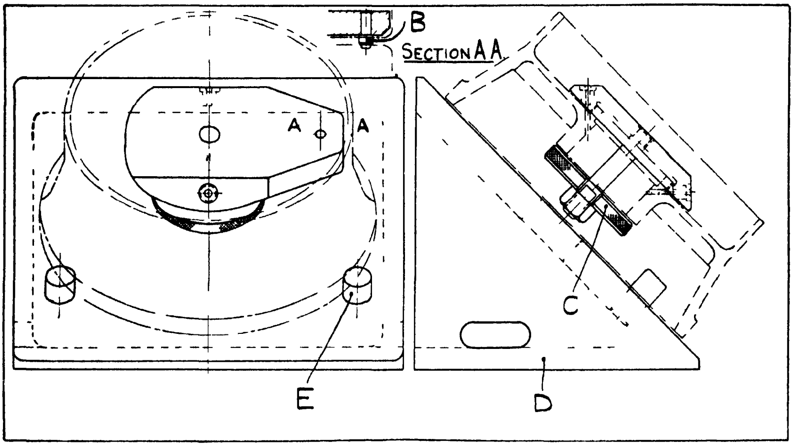


Fig. 5.—LOCAL JIG WITH ANGULAR BASE

This being an example of a simple welded jig, there are several points which may be raised both for and against this type of jig. It is a convenient method of construction where jigs are wanted quickly, but furnaces should be available for normalising after welding to prevent the distortion which would otherwise occur as the strains set up in the material are gradually released. A steel jig is no doubt stronger than a cast-iron one for a given section, but is liable to take a permanent set should it be dropped, whereas a cast-iron jig submitted to like usage would possibly break and so avoid future scrap work.

It is not considered that welded construction will ever supersede cast iron, since, although lightness is an important consideration in the design of drill jigs which have to be moved about by the operator, the extra weight associated with cast iron proves useful on certain classes of tool work, as, for example, on milling fixtures, in which it is required to damp out vibration.

Although for a simple construction welding may be the cheaper, if a welded jig is at all complicated, arrangements must be made to hold the various parts in position whilst welding them together, whereas the patterns and the cast iron used on jig work can be obtained cheaply, particularly since jig patterns do not require first-class workmanship.

Local Jig with Angular Base

In Fig. 5 is shown a local jig for drilling two oil holes after the other drilling on the component has been completed. Location is provided by a register in the jig and a pin (*B*) locating in a previously drilled hole.

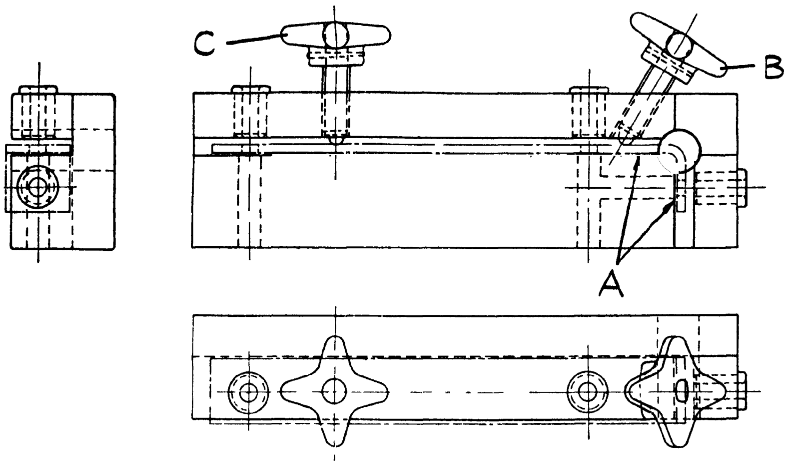


Fig. 6.—Jig milled from solid

The jig is clamped to the work by means of a "C" washer marked *C*, which obviates the necessity for removing the nut each time the component is removed. The angularity of the holes is obtained by supporting the component on the angular base by two stop pins (*E*), which act as a vee block. The component is rotated to bring one or the other of the drill bushes beneath the drill, this method having proved sufficiently accurate for drilling the oil holes in question.

If it is required that the holes be drilled accurately, then a positive form of index must be provided, in order to bring the drill bush in line beneath the drill and to avoid deflecting it whilst drilling, without relying on the judgment of the operator. The requirement of this accuracy would necessitate the component being mounted on an index plate, of which one type is shown in the example of an indexing jig seen in Fig. 19.

Jig milled from Solid

For a small component the jig may often be milled from solid, and an example of this is shown in Fig. 6. It is necessary on this jig to locate from the inner faces (*A*) of the component, and to this end one of the two clamping screws is inserted at an angle as shown at *B* and tends on tightening to press the component against both faces of the jig. The other clamp screw (*C*) should be tightened after the angular one.

Another point brought out by this jig is that provision should always be made for the drill to break through the work, and clearance holes are shown for this purpose which pass right through the jig body to avoid the formation of swarf traps.

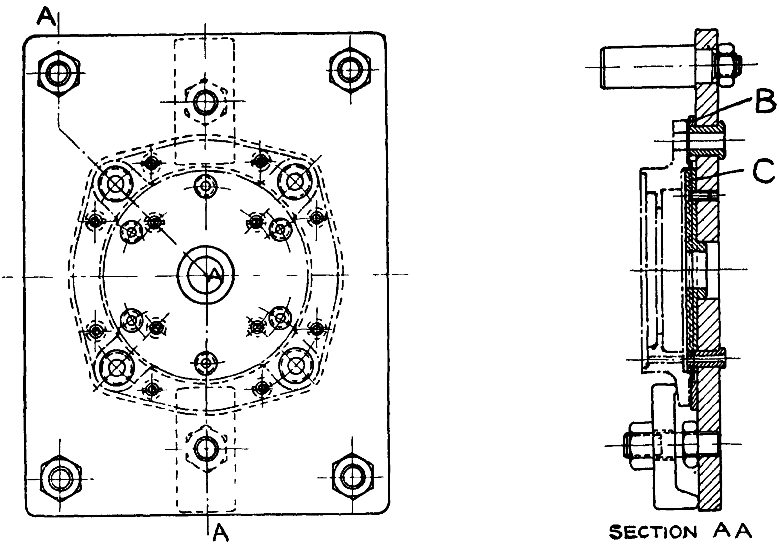


Fig. 7.—Jig with profile plate

The jig as shown is not foolproof, since it is necessary for the operator to press the component against the two locating faces in the jig, and the angular clamp screw serves only to assist in maintaining this position. If the jig is to be made for use by unskilled operatives, it would be advisable to provide some form of two-way clamping to remove the responsibility for correct location in the jig from the operator.

Sighting-plate Jig

Fig. 7 shows a very useful method of locating a component in a jig by the use of a profile or sighting plate. The usual arrangement is to have a thin steel plate (*B*) interposed between the drill plate and component. The plate is made to the same profile as the component, as shown in the figure, but is approximately $\frac{1}{16}$ in. larger all round, enabling it to be seen outside the contour of component. Then, by the operator sighting the component in its best average position on the plate before clamping, the holes are subsequently drilled with an even amount of metal surrounding them. It will be seen that this device is only useful, in the main, on unmachined profiles, since if the profile is machined, a positive location may be provided by other means.

In the example shown the component is located centrally by means of a spigot (*C*) in the previously machined bore, and the profile plate serves only to provide a radial location. This principle will apply to

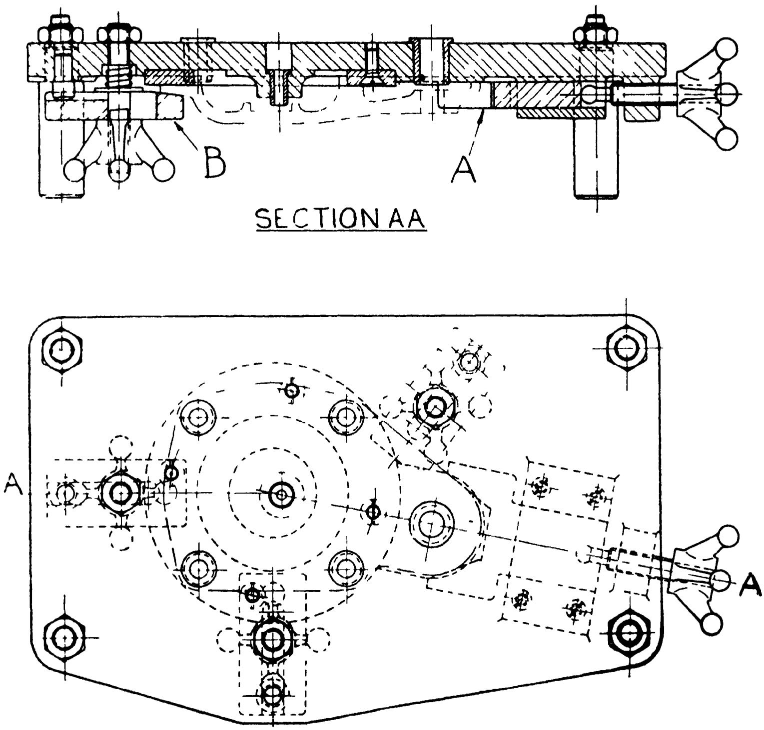


Fig. 8.—JIG WITH SLIDING VEE LOCATION

most drill jigs using sighting plates, since it will usually be the case that one or more machining operations have been performed previously to drilling. Advantage must be taken of any machined locating points thus provided, and the sighting plate will then be used for obtaining additional locations necessary for drilling.

Sliding Vee Location

The jig shown in Fig. 8 is included in order to show the application of two of the jig details dealt with in an earlier chapter. These are the sliding vee location (*A*) and the ordinary type of strap clamp (*B*) with a heel pin to prevent rotation. This clamp is one of the most common in use on jig work and provides a cheap and effective method of clamping.

It will be seen that the sliding vee locates on the projecting lug and serves as a radial location, the component previously having been positioned by means of the spigot, which locates in a hardened steel ring.

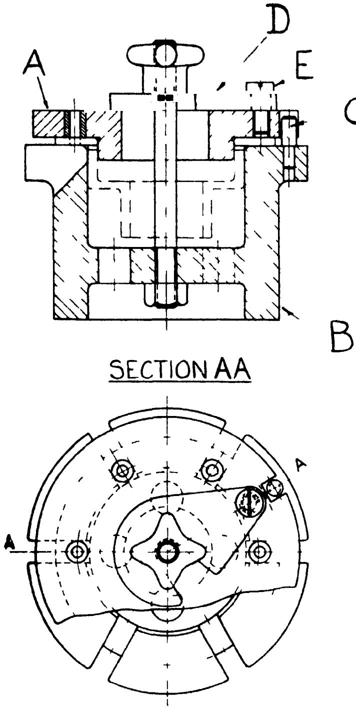


Fig. 9.—Pot-type jig

It is essential on this component that the hole in the lug should be central, and for this reason the lug becomes the controlling feature in the location whilst the holes in the flange find their own position.

Pot-type Jig

A pot-type jig is shown in Fig. 9, this type being convenient for a small circular component, and the example shown has several interesting points in its construction. The jig proper is the bush plate (*A*), which also provides the locating spigot, and could, at a pinch, be used without the pot (*B*) if a cheap jig is required. The pot is provided to give adequate support while drilling. It should be noted that it has slots to coincide with the drill bushes for the clearance of swarf and burrs pushed through by the drill. For the same purpose a series of holes is provided at the bottom of the recess. To ensure that the drill bushes and swarf slots coincide, a rough locating pin (*C*) is provided which fits loosely into a slot in the edge of the bush plate.

Clamping is by means of a captive " C " washer (*D*), which is held loosely by a shouldered screw (*E*) to prevent loss. The washer is swung aside, after loosening the clamping nut to allow the nut to pass through the central hole in the bush plate.

Latch Jig

Fig. 10 shows a latch type of jig for drilling two oil holes diametrically opposite between the teeth of a bevel gear-wheel. The latch (*A*) is located by means of a thumb screw (*B*), and it may be noted that the dimple in the latch, into which the screw locks, is drilled slightly higher than the centre line of the locking screw, thereby causing the latch to be forced down on to the stop pin (*C*).

The drill bush (*D*) is chamfered on the end to locate easily between the teeth of the gear and a pointer (*E*) is provided by which the first drilled hole is sighted when locating the bush for drilling the second hole.

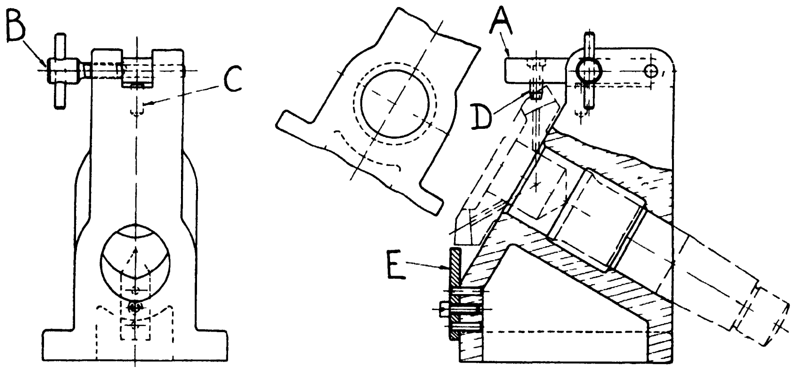


Fig. 10.—LATCH JIG

Box Jigs

Probably some of the most awkward components as regards drilling are the endless variety of small brackets which are encountered in most branches of engineering and which often require drilling in two or more planes. Following are two examples of this type of component which will help to give a lead on this class of work.

The first example, shown in Fig. 11, is a simple example of a second operation drill jig, the three holes in the base having been drilled previously. Clamping is effected by means of a strap (*A*), which carries a compensating pad (*B*) to ensure even clamping. The strap is locked by a hook-type cam, which is quite common on this type of jig and proves very effective where great clamping force is not required. The component is located in the jig by two pins locating in holes in the base of the component, one of which is relieved to locate on one diameter only, this being a method used to allow for variation in the centres of the drilled holes and still provide positive location.

Fig. 12 is a more complicated example of the type of jig shown in the previous example and combines several interesting features. The jig is for drilling two bolt holes (*A*) in the base of the bracket and for drilling and reaming two cross-holes (*B*) for which latter purpose slip bushes (*C*) are provided which are the correct size in the bores to accommodate both the drill and reamer in turn. The component is located firstly by the support block (*D*) in the gap between the two bosses, the distance between these bosses having been milled in a previous operation. The bush plate (*E*) is then swung into position and locked by means of the hook-type cam.

In locking the bush plate the bosses on the component are pushed into two spring-loaded vees (*F*), which serve to locate it endways in line with the slip bushes. The two vees are then locked by means of the hand lever

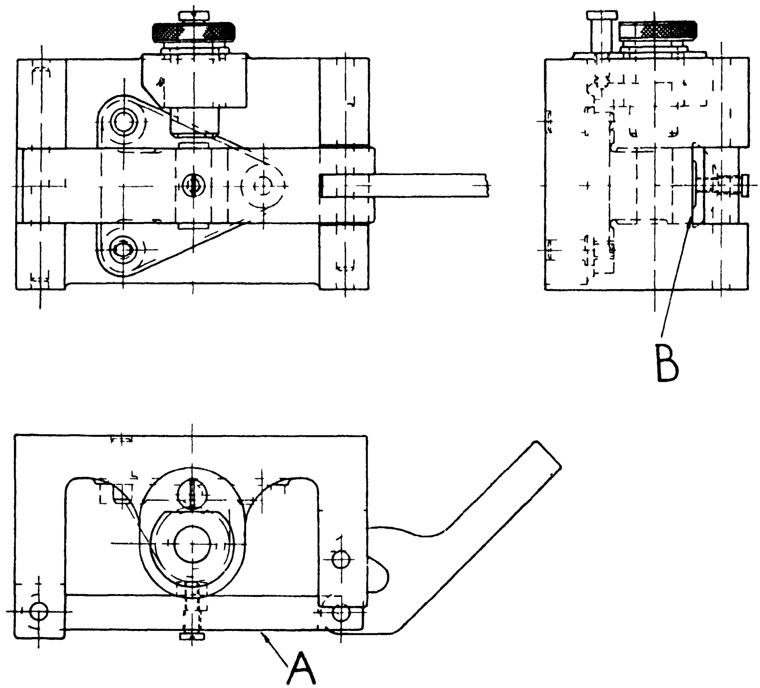


Fig 11 —Box JIG

shown at *G*, which operates a pad bolt It will be seen from the figure that adjacent to the upper slip bush a pin (*H*) projects into the jig and provides a foolproof or fouling device used to prevent the component being loaded the wrong way into the jig Fouling pins are necessary in any jig where it is possible to load the component in any but the correct position, and this is extremely important when designing jigs for use with unskilled labour

Two-way Clamping

The jig shown in Fig 13 is included to show an example of a type of two way clamp It is required to clamp a small square component into the angle of the jig to obtain accurate location from two faces This is achieved by the swinging clamp piece (*A*), which exerts a force in two directions on tightening the hand knob (*B*) The cross hole through the two lugs of the component has to be reamed in line on both lugs, and to ensure this a reaming bush (*C*) is fitted to the locating block which fits between the two lugs

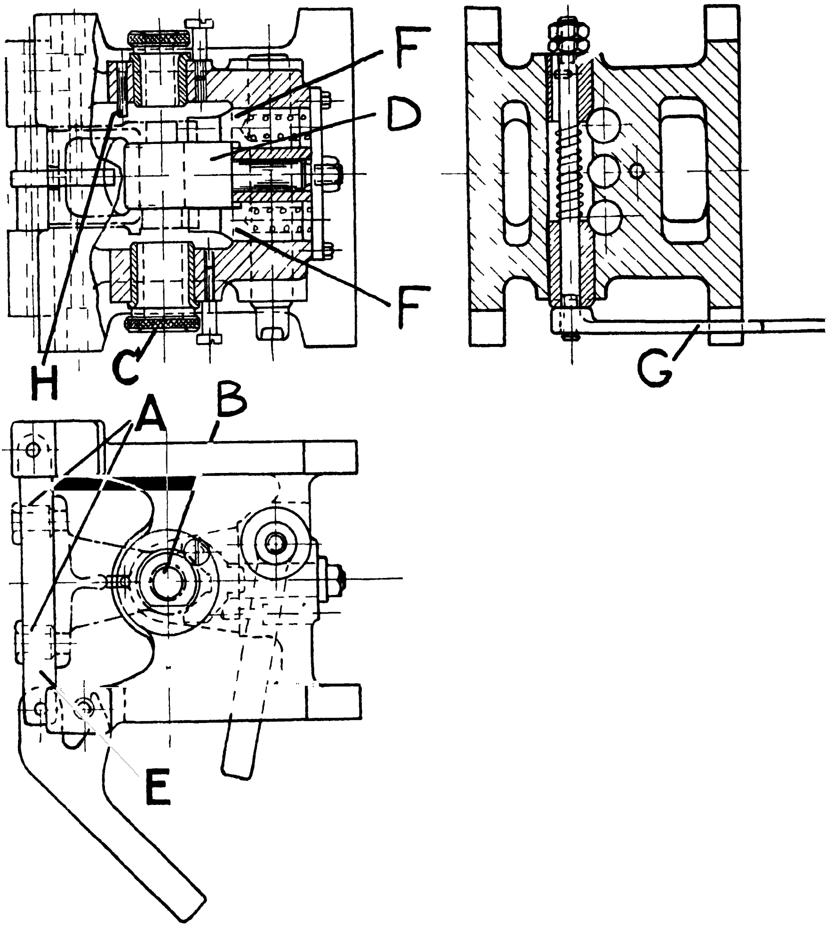


Fig. 12.—Box jig

A more accurate method of lining up these two holes would be to provide slip bushes for drilling and reaming from both sides of the jig, but this would add to the cost of the jig. In order to prevent distortion of the component whilst drilling the second lug, a bolt with an eccentric head is provided at *D*, on to the shank of which is pinned a hand knob. After the component is inserted, the knob (*B*) is turned and causes the eccentric to lock against the bottom face of the component, thus providing a stop to take the pressure of the drill.

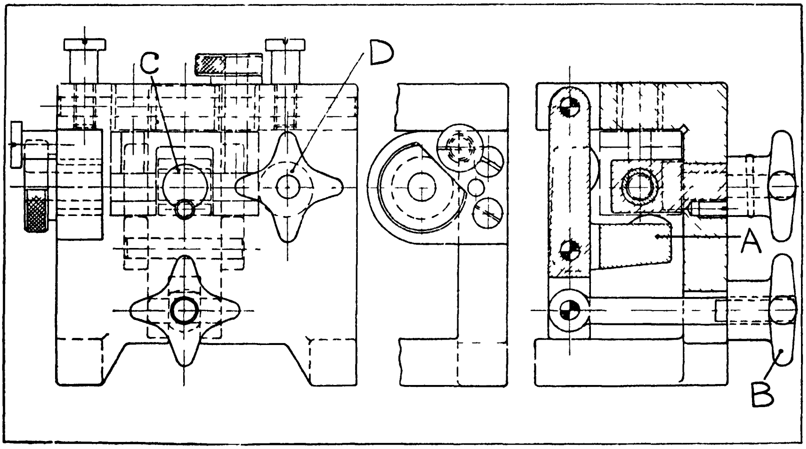


Fig. 13.—Box jig with two-way clamping

Jigs for Large Components

When drilling large components, to attempt to provide the type of jig which we have so far considered, in which the component is clamped into the jig and the whole is a portable unit, would result in jigs of weights and dimensions such as to make them unmanageable. It is usual with large components either to provide a jig which is bolted to the machine table or to have local jigs which are attached to the component after the latter has been bolted to the machine.

Fig. 14 shows a jig for a gear casing which consists of a base (*A*), which is bolted to the drilling-machine table and locates the component together with a separate jig (*B*), which is afterwards placed in position. It is possible with jigs of this type to use several drill plates with the same base, this being useful where a face has a large number of holes to be drilled, each plate then carrying its own complement of bushes. It will be seen in the figure that the location is in the bearing bores of the component. Clamping is by the use of long bolts (*C*), which are quickly detachable from the base as at *D* and are released at the top by captive "C" washers (*E*). The two lifting handles shown prove very useful on this jig, which is just within the limit of manual handling.

Jig for Multi-drill

Fig. 15 shows a drill jig for use with a multi-drilling machine. The base (*A*) is bolted to the machine table and carries two spigots (*B*) to locate the component. Due to the weight of the component and the fact that the holes being drilled are quite small, the component is not clamped, but rests on the base by its own weight. The drill plate is hung on the drill head of the machine by the four lugs (*C*) and moves up and down

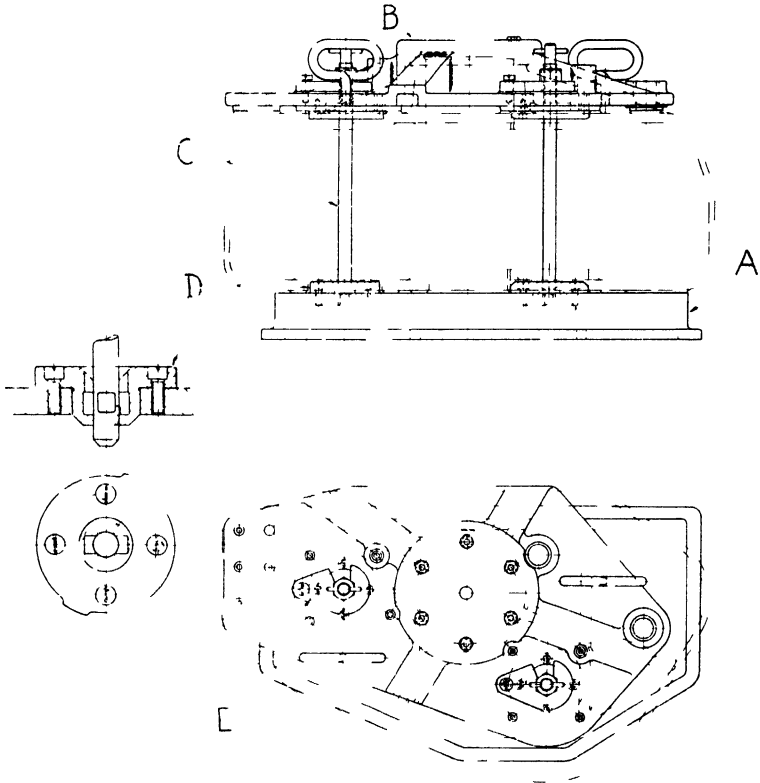


Fig. 14.—JIG FOR GEAR CASING

with it, being located in relation to the component by the two locating pillars (*D*) which pilot in the jig base, and also by the two plates (*E*) on the underside which locate in slots in the component.

In operation the drilling machine head, carrying the drill plate, is raised clear of the work and the component is located on the base. The drill head is then fed down until the locating pillars pilot into the base and the drill plate rests on top of the component, the drills continuing to feed down through the bushes to complete the drilling operation.

As a point of interest, Fig. 16 shows the method of laying out the spindles of the drilling machine in order to check the various clearances between the spindles and brackets. On work of this type, the holes are often grouped too closely together to be drilled in one setting, being closer than the minimum working centres of the drill spindles.

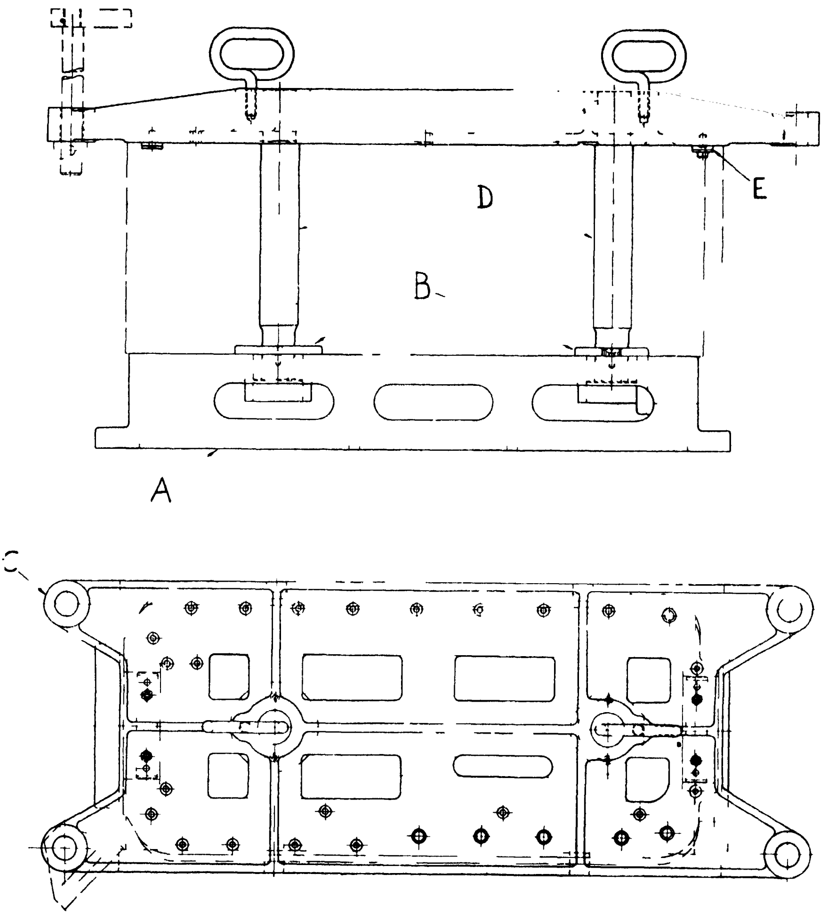


Fig. 15.—JIG FOR USE ON A MULTI DRILL

In such cases it is quite common to either split the operation into two on the multi-drill or to drill as many holes as possible on the multiple machine and then complete the drilling by the use of local jigs on a single spindle machine.

In Fig. 17 is seen a local jig for the same component as that shown in Fig. 15. The jig is for drilling holes on the side of the component and location is taken from two of the holes (*A*) drilled in the multi-drilling operation described above. It will be understood that it is necessary either to bolt the component to an angle plate before assembling the

local jig to it or to provide a cradle to support the component in the correct drilling position.

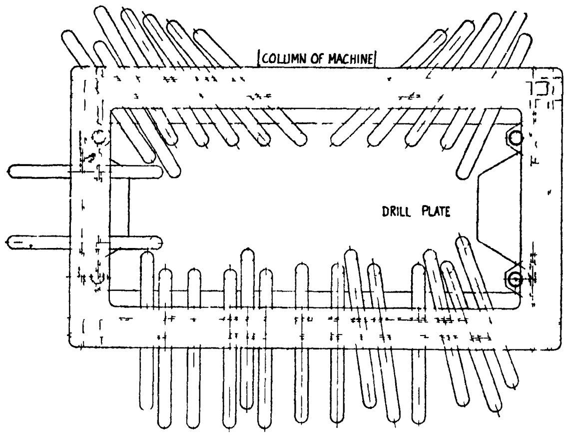


Fig. 16.—Layout of drill spindles on a multi-drill

Trunnion Jig

Another method of handling large components for drilling is by the use of trunnion-type jigs, an example of which is shown in Fig. 18. The jig proper carries trunnions at its ends, which rotate in cast bearing brackets (*A* and *B*), the two brackets being mounted on two lengths of standard channel iron

Two cams (*C*) are provided for locking, these being pinned to a common spindle and locked by a hand lever (*D*). The cams lock on any of the four faces of the square block (*E*) shown at the end of the jig and serve to line the jig up before drilling. In operation the jig is locked in the position shown to enable the component to be easily located and clamped in position.

Then, after clamping, the cams are released, the jig rotated through 180° to bring it to the drilling position, and the cams locked again for drilling. The component is located in this jig by the use of sighting plates (*F* and *G*) at either end, and three adjustable stop screws (*H*, *J*, and *K*) are used for steadying the component whilst clamping.

In addition, these screws are set by the operator to the average of the batch of castings being drilled and help to save time taken in sighting each piece separately. It becomes necessary, therefore, to alter the screws only when the sighting plates show that a casting varies beyond the normal from the ones previously drilled.

Indexing Jig

Fig. 19 is an example of an indexing type of drill jig. It is used for drilling three holes (*A*) in the machined seating on the component ; also two pairs of bolt holes (*B*), each pair at an angle to the centre line and two pairs of blind holes (*C*) on the sides. In addition the four bolt holes (*B*) are to be spotfaced on the underside. Consequently, in the index plate (*D*) are eight bushes (*E*), which are used as follows :

Bush No. 1.—Load component into jig.

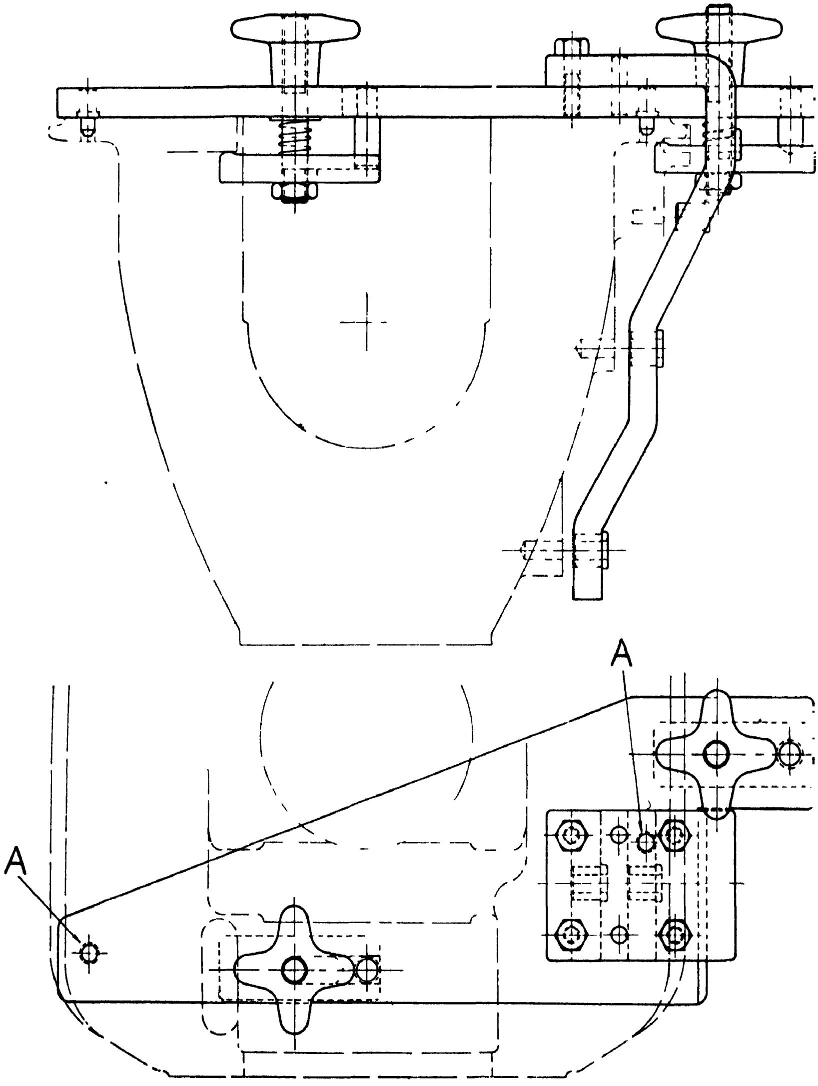


Fig. 17.—LOCAL JIG FOR A LARGE COMPONENT

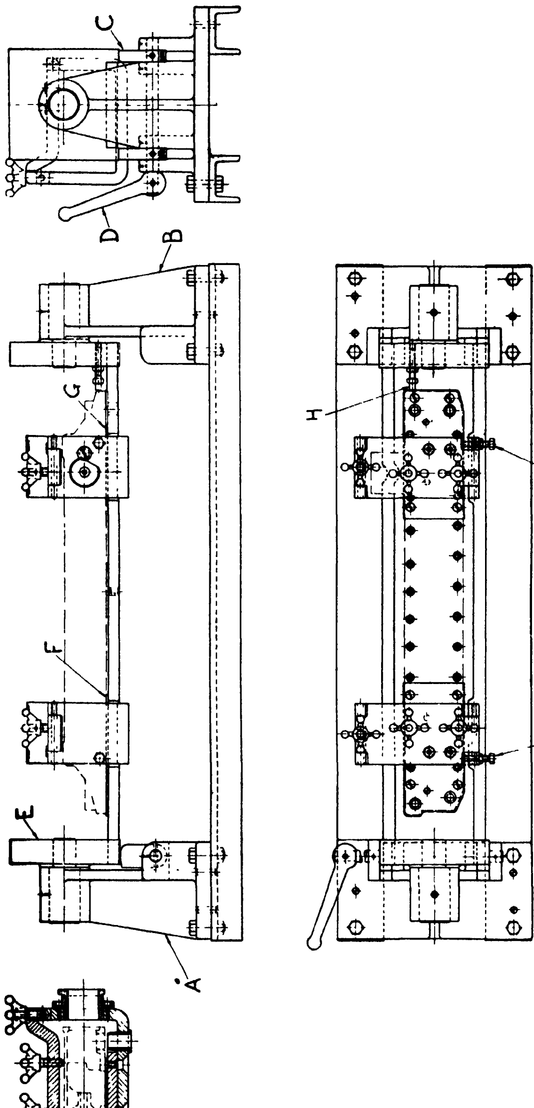


Fig. 18.—TRUNNION JIG

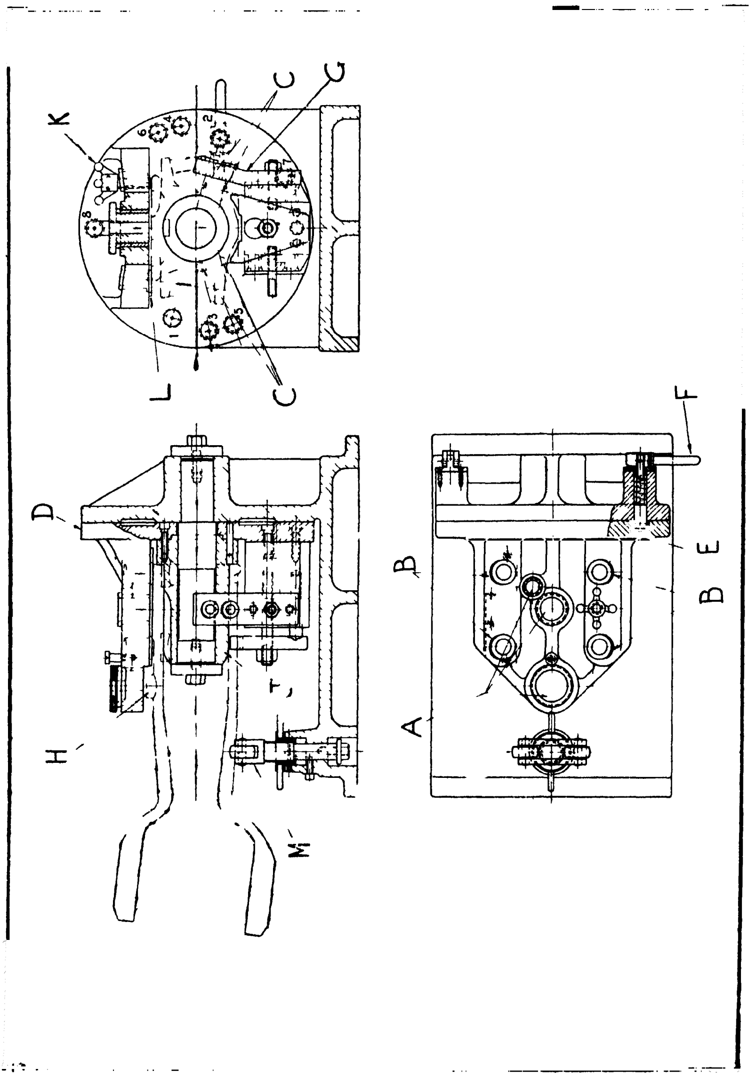


Fig. 19.—INDEXING JIG

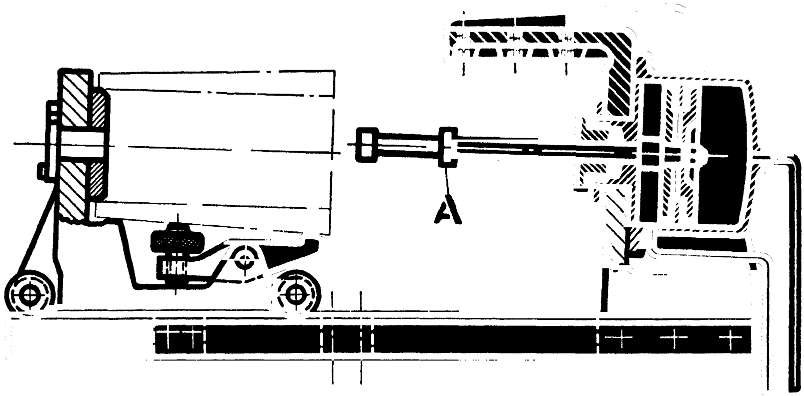


Fig. 20.—Air-operated jig for a heavy component

Bush No. 2.—Drill three holes in machined seating.
Bush No. 3.—Drill left-hand pair of bolt holes.
Bush No. 4.—Spotface left-hand pair of bolt holes.
Bush No. 5.—Drill right-hand pair of bolt holes.
Bush No. 6.—Spotface right-hand pair of bolt holes.
Bush No. 7.—Drill left-hand side holes.
Bush No. 8.—Drill right-hand side holes.

In order to space the index bushes sufficiently far apart to allow for using a reasonable diameter of index pin, two such pins (*F*) are provided, each of which locates in certain of the bushes, the two pins being on different pitch radii to avoid locating them in the wrong index bushes. The two pairs of blind holes (*C*) on the sides of the component are drilled by means of a detachable drill plate (*G*), which is held in position by a single nut and located by two pins which push into bushes in the main jig. The drill plate (*G*) is used for both pairs of holes, *C* being moved from one side to the other, and is necessarily detachable to allow the component to be loaded into the jig. It is required to spotface the boss (*H*), and for this reason a slipbush is provided which is removed to allow for the insertion of a spotfacing cutter.

The component is located by a spigot (*J*) in the bore, which has been previously finish bored; and angular location on the spigot is obtained by clamping the milled face in which the bolt holes are drilled on to a rest plate (*L*) by tightening the hand screw (*K*) which swivels the component about its axis. As the component when located and clamped has a large overhanging weight, a roller jack (*M*) is brought into operation before drilling commences to act as an added support and to prevent excessive drilling pressure on the spigot.

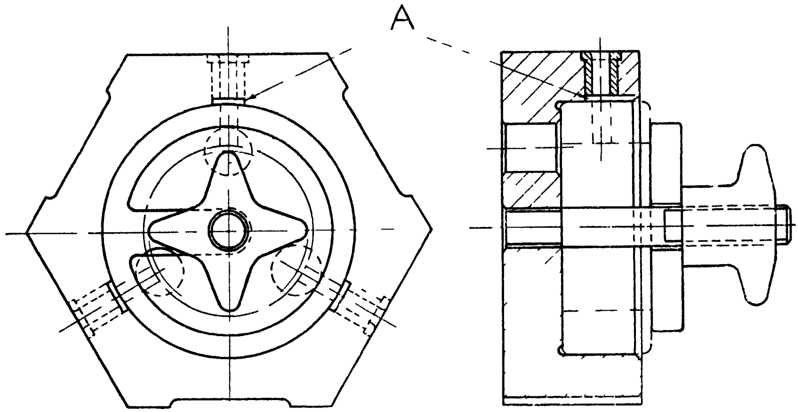


Fig. 21.—" Burr slots " in a jig

Air-operated Jig

Another way of handling a heavy component is shown in Fig. 20. Twenty-four holes have to be drilled in the side of this component, which is too heavy to be lifted directly into its position in the drill jig. It is necessary, therefore, to provide an arrangement to assist in the handling of this piece, which is 3 ft. 6 in. long.

The component is lifted from the floor by an air hoist and is dropped on to skates, which run on two rails beneath the jig. The section shown in the figure occurs at two positions along the jig.

So that the component can be adjusted to approximately its correct height for the machined bores to engage with the locating spigots, compensating rockers on the skates are set slightly on the low side, so that when clamping, the component is lifted off the rocker by the tapers on the locating plugs. The component can thus be easily run under the drill bushes and over the clamping bolts which are attached to the pistons of air cylinders.

The hinged slotted washer is then slipped under the bolt heads and clamping is done simultaneously at both ends by operating an air valve.

The action of clamping lifts the wheels of the skates off the rails by raising the skate body ·020 in. on to hardened plates, thus providing support and positive height location for the component.

To remove the component from the locating plugs in the jig, a shoulder is arranged at *A* on the clamping bar which, upon reversing the air valve, forces the component from the locating plugs, thus relieving the operator of the fatigue of the manipulation which might be otherwise required. The automatic ejection of components should be studied by jig and tool

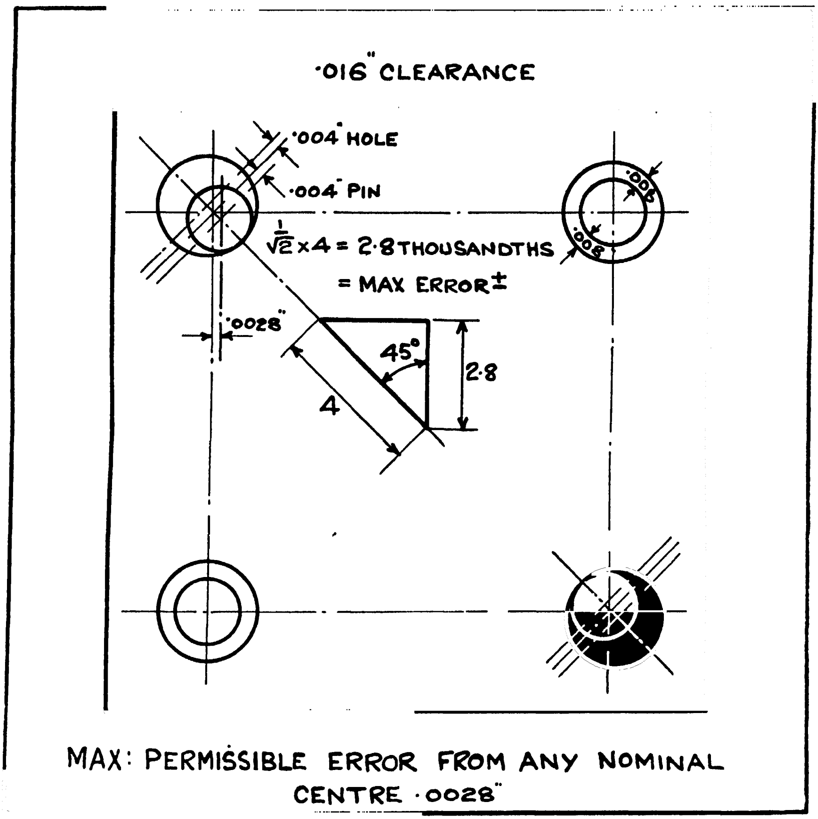


Fig. 22.—CALCULATING THE TOLERANCE ON CENTRES OF BUSHED HOLES

designers and applied wherever possible ; an example, such as the one just described, wherein air clamping is used provides a simple method of achieving this ejection. It often takes longer to remove a component from a jig than to machine it.

Whilst on the question of removing components from the jig, the designer should remember that when a hole is drilled, a burr is thrown up round the edge of the hole. Therefore care should be taken when designing a jig that the component can be withdrawn *after* drilling by the provision where necessary of burr slots as shown in Fig. 21 at *A*.

In our examples of drill jigs we have refrained from giving examples of mass-production tooling. The designer will realise that, having

absorbed the principles of jig design, he may apply these principles to any class of work. That is probably the essence of jig design—learn to apply the principles.

Jig-bush Centre Tolerances

It is not proposed to discuss in this section the various types of bushes which are used in drill jigs. Similar types of bushes are also used in various boring fixtures, etc., and the whole is fully dealt with under the section headed "Jig and Fixture Details." It is necessary, however, to understand clearly the method of deciding the tolerances to which the centres of bushed holes should be bored, as it must be appreciated that there is a direct relationship between the cost of a jig and the accuracy called for on the tool drawing. The closer the tolerance, the greater care and time required for manufacture. This is the case even though high-precision jig-boring machines are used for the boring operation. Many jig drawings are submitted to tool manufacturers calling for much closer tolerances than are actually required, in some cases even down to a centre distance with a tolerance of ·0001 in., whereas tolerances of several thousandths would be equally satisfactory on the work to be machined. Give the man who has to do the estimating the opportunity to ascertain the economic value of a jig, otherwise one may pay too highly or be disappointed upon delivery.

The correct amount for the tolerance can be determined in the following manner, the method being shown diagrammatically in Fig. 22.

Suppose, for instance, the clearance between the hole and the bolt, stud, or shaft passing through it is dimensioned as $\frac{1}{64}$ in., which, for convenience sake, we will call ·016 in.; if it were possible to ensure that error would occur along one line from the datum point only, then by drilling the stud hole ·004 in. to the left, and the clearance hole ·004 in. to the right of the given dimension, the bolt would be actually touching the side of the hole.

As this condition rarely occurs, one must take into consideration the co-ordinates forming the triangle with holes in any other position, and as the greatest distance difference would occur at 45°, it is permissible to allow only $\frac{1}{\sqrt{2}}$, which is approximately 70 per cent. of the 4 thousandths, or 2·8 thousandths either side of the nominal centre.

To keep slightly within this, therefore, the errors on the jig should not exceed plus and minus ·002 in., which is a tolerance equalling one-fourth only of the clearance between the bolt and the hole. Even with this tolerance, if errors occur at the maximum in either direction, the clearance will only be 1·6 thousandths of an inch on the centre distance.

Chapter XII

MULTI-SPINDLE DRILL HEADS

WHEN a drilling operation comprises the drilling of more than one hole in a component, the drilling time may be reduced substantially to that required for drilling the holes singly by equipping the drilling machine with a multi-spindle drill head. Such heads are expensive to produce, but the tool executive will find that, where sufficient quantities of work are required, the use of multi-heads will effect substantial economies. The foregoing remarks assume that there are not available suitable multi-drilling machines, as such, which could have their spindles set to the required centres.

These heads are also useful when used in conjunction with multi-station fixtures ; for instance, a hole may require to be drilled, spotfaced, and reamed, and, by the use of a three-spindle head together with a four-station indexing jig, the operation could be performed progressively on three components. The fixture in this case would be arranged as follows :

1st station : load component.
2nd station : drill.
3rd station : spotface.
4th station : ream.
1st station : unload and load new component.

Another useful application of multi-heads is on certain types of production boring machines, in which the boring bars are driven by heads having their spindles spaced at the correct centres to line up with the bushes in the boring jig, thus relieving the operator of the necessity for obtaining the correct spacing of the various boring bars, and saving the considerable expense so often entailed in setting the machine. An example of this type of head is shown in Fig. 5, described later on.

When designing a head for use with drills of varying sizes, it is important that the various spindles should be geared in such a manner as to cause the drills to rotate at their correct relative peripheral speeds for efficient cutting. By varying the speed of the drilling-machine spindle, the speeds of the drills may be altered to suit different materials, but still remain in correct relation to one another. It is important to provide adequate lubrication for drill heads, the usual procedure being to run the gears in oil and, where ball bearings are used, to provide oil seals on the spindles to prevent leakage of oil from the bottom of the casing.

In a works where multi-heads are used in large numbers, it is worth while standardising the actual drill spindles together with the appropriate

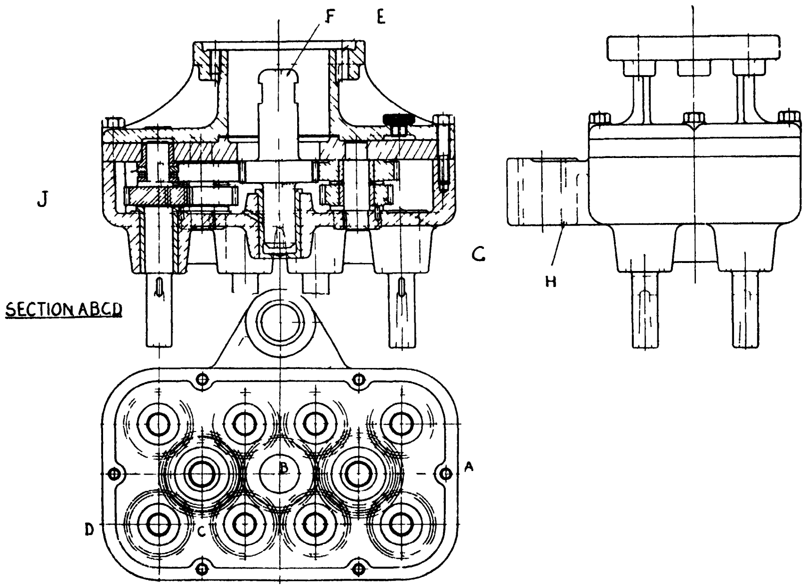


Fig. 1.—EIGHT-SPINDLE DRILL HEAD

ballraces, or bearing bushes, thrust bearings, and oil seals. It is suggested that three sizes of standard spindle would cover the range of drills normally in use in most factories.

Mounting a Multi-head

A multi-head may be mounted on to the machine either by attaching it to a flange on the machine spindle or by providing the head with a sleeve which fits over the sliding quill of the machine, the head in this case being held in position either by pad bolts or by splitting the sleeve and tightening by means of a clamping bolt. When a drilling machine is installed solely for use with multi-heads, it is recommended that the flanged type of mounting should be specified. The multi-head can then be spigoted to the flange on the machine spindle. To facilitate lining up the drilling jig or fixture on the machine table, it is of advantage to provide guide bushes in the drill head which locate over pillars set in the jig. If the plate holding the drill bushes is of the type carried up and down on the drill head, this plate can also be guided on the same pillars, and spring loaded on to the top of the component to steady or hold it down whilst drilling.

Designing Multi-heads

It is important when designing multi-heads that adequate provision is made for supporting the thrust of the drill spindles. Examples are quite

common where, due to the combined thrust of several drills, the casing of the head is distorted and eventually cracks. Although the thrust of each spindle may be taken on a ball-thrust washer, unless adequate support is available failure may be expected.

It will be noticed that in the heads shown in Figs. 1, 2, and 4, a support plate is inserted between the top of the gear casing and the supporting member. This plate takes the drill thrust in one of two ways, either through the thrust races arranged directly beneath it, as shown in Fig. 1, or through the gear casing bolted to it, the plate serving to stiffen the whole assembly. If this method is used, the gear casing must be rigid enough to support the thrust, and the walls of the casing should be arranged as closely round the spindles as is practicable. This is the reason for the rather odd-shaped gear casing shown in Fig. 4. If the construction shown in Fig. 1 is adopted, the gear casing may be lightened considerably, since it is not called upon to support the thrust of the drills. The casings of most heads, unless they are for heavy duty, may be cast in aluminium for the sake of lightness.

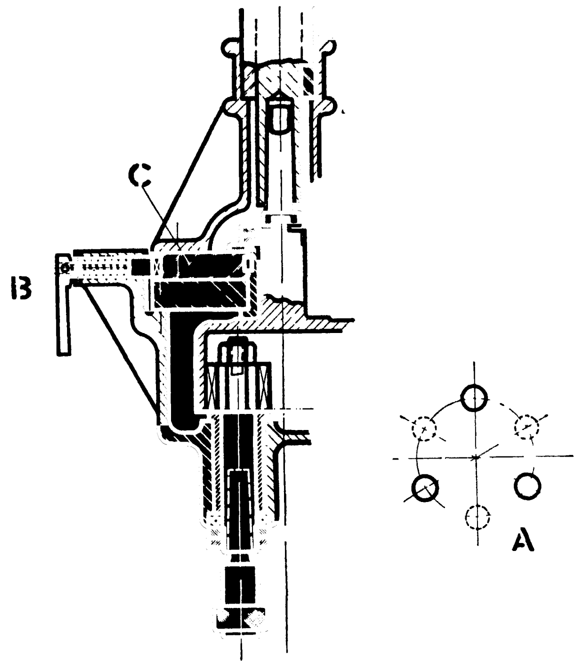


Fig. 2.—SWIVELLING THREE-SPINDLE DRILL HEAD

The train of gears in a multi-head should be arranged, wherever possible, so that all the spindles rotate in the same direction as the machine spindle, and right-hand cutting drills used. Where, due to complication of the gearing, it becomes relatively impossible to arrange all the drill spindles for right-hand cutting, left-hand drills may be used. Their use should, however, be avoided wherever possible, as great care must be exercised by the operators on heads where they are used, in order that drills are not inserted in spindles having the wrong direction of rota-

tion. A drill head may sometimes be simplified by reversing the spindle of the drilling machine in order to obtain the required direction of rotation of the drill spindles.

Eight-spindle Drill Head

Fig. 1 shows a straightforward design of head having eight spindles. The head is for use on a machine with a flanged quill and the top of the casing has a recess to suit the flange. A dowel is fitted at *E* to prevent "fretting" or vibration of the bolts used for securing the head. The spindle of the machine is fitted with a quick-release chuck and the driving gear *F* of the head has a shank suitable for this type of drive. This facilitates the coupling up of the machine drive to the drill spindle.

Due to the closeness of the spindles, it is necessary to drive through a compound train of gears, the drive from the main gear being taken through two compound idler gears *G*, each of which drives four of the spindles. At the rear of the gear casing is cast a lug in which is fitted a bush *H*, which is used for retaining the head in correct alignment, and prevents radial movement. The bush slides on a guide pin, which can be fitted either to the column or to the table of the machine. The thrust of the drills is taken on the thrust races *J* and through the casing on to the machine flange.

The examples which follow are included because each embodies some special feature in design and has provided a satisfactory solution to the problem involved.

Swivelling Drill Head

Fig. 2 shows a part section of a head designed for drilling three holes, equally spaced on a pitch circle, at either end of a component. The component and jig together are too heavy to be turned over by hand. The jig is therefore arranged on trunnions, so that after one side has been drilled the jig plates and the component can be swung over and the operation repeated at the opposite end.

It will be realised that swinging through 180° brings the three holes into a position opposite to the original setting, as shown in the diagram at *A*. This could be overcome by twisting the whole jig round, but it is too heavy to make this an easy operation, especially as it would have to be accurately located beneath the multiple-drill head in both alternative positions.

It is arranged, therefore, in order that neither the jig base nor the drilling-machine spindle needs resetting during this operation, that the casting carrying the spindles on the drill head can be indexed the correct amount around the driving spindle.

This is achieved by providing a lug to accommodate an indexing plunger (shown at *B*) on the casting carrying the drill spindles, and arranging two slots in the plate *C* between the top and bottom halves of

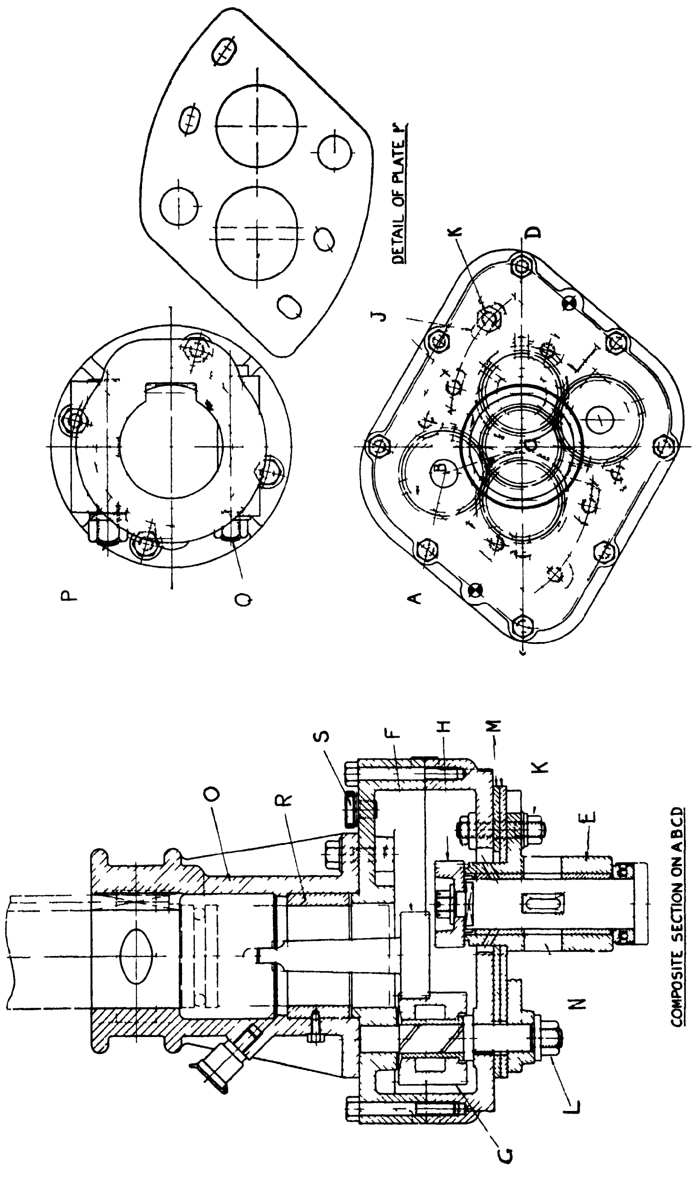


Fig 3.—Two-spindle head with adjustable centres

the drill head, so that on releasing the plunger at *B*, the bottom portion of the head is free to swivel into its other position.

The thrust of the head is taken immediately beneath the quill of the drilling machine. The drive from the machine spindle is floating through the dogs beneath the morse taper shank. Due to the closeness of the three spindles the main drive consists of an internal gear which drives the three gears on the drill spindles.

In this example the head is bolted to the stationary quill of the drilling machine and is held in position by a pad bolt.

Head with Adjustable Centres

The head shown in Fig. 3 is for drilling two holes and is designed for use on two different components, on which the centre distances of the holes are 90 mm. and 100 mm. respectively, necessitating an adjustment of 10 mm. on the centres of the spindles in the head. This adjustment is obtained by mounting each of the spindles in a separate holder *E*, the two holders being bolted to the bottom face of the gear casing. The drive to the spindles is taken from the driving gear *F* on to the two gears *G*, and thence to the spindle driving gears *H*. The spindle holders are arranged to pivot on the same spindle as gear *G* and, as may be seen in the plan view, gears *G* and *H* act as a sun and planet and three gears always remain in mesh. The holders are limited in their movement by the slots *J* cut in their fixing flanges.

To adjust the spindles it is necessary to loosen the four nuts *K* and also the two marked *L* on the idler gear spindles. A trouble generally experienced on drill heads with adjustable spindles is that of retaining oil in the head. In this head the problem is accentuated by the necessarily large diameter of the drill spindles—these being for 1¼-in.-diameter drills—the closeness of the spindle centres, and the comparatively large adjustment required.

The following method is adopted for retaining the oil. Two steel plates *M*, which are ground flat and parallel, are interposed between the bottom of the gear casing and the flanges on the spindle carriers ; these plates are also shown in the detail drawing. The two are identical, but one is reversed when assembled to the head, and the holes therein are so arranged that one or the other of the plates is always covering the holes in the gear casing, whichever position the spindles are in, so preventing any leakage of oil. In practice it is found that the only leakage which occurs is a slight trickle through the spindle bearings, sufficient to ensure that these are properly lubricated. When adjusting the spindles, the nuts should only be slackened off sufficiently to allow the spindle holders to be moved, otherwise oil will be lost from the casing.

In order to shorten the overall length of the head, the drift slots for removing the drills are cut through the spindle carrier and bearing bush at *N*, thereby avoiding the overhang of the spindles which would other-

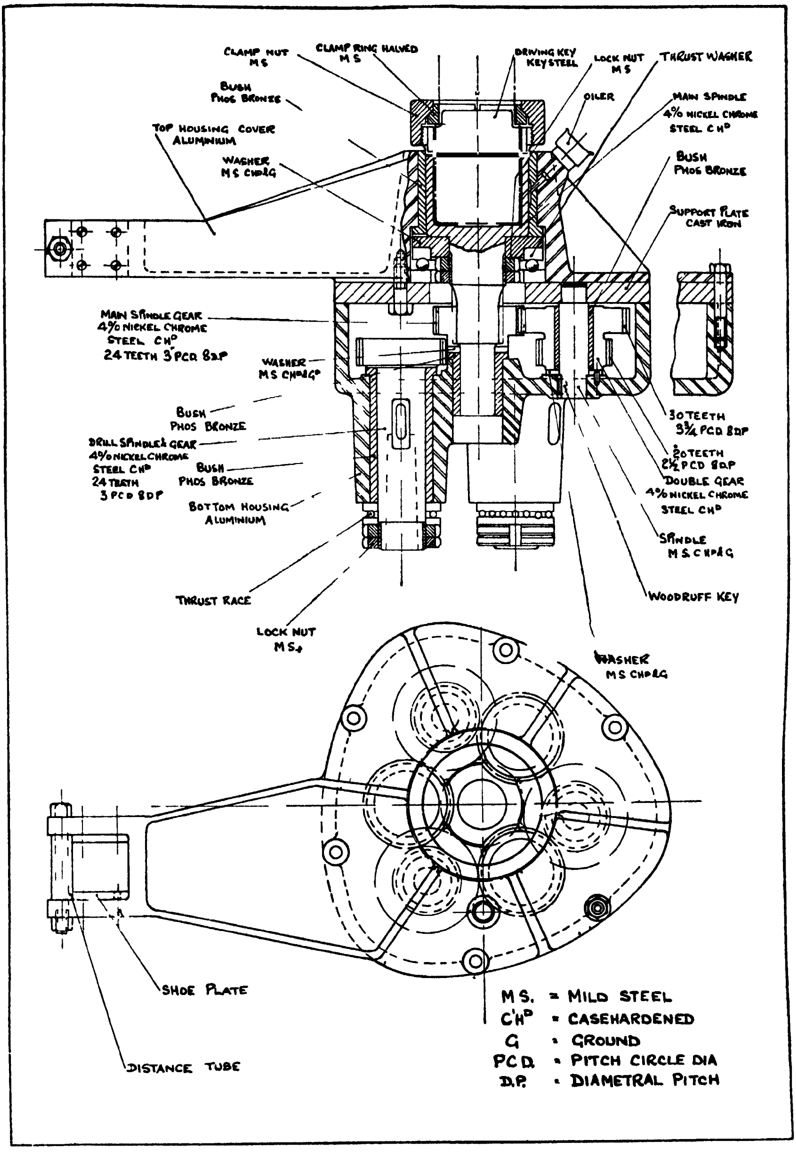


Fig 4 —DRILL HEAD WITH TORQUE ARM

wise be necessary. On top of the gear casing is mounted a sleeve *O* which is used for attaching the head to the drilling machine. Two bolts are used for fixing, the one at *P* being a pad bolt to grip the machine quill, and the other at *Q* a plain bolt which is used to take the drilling thrust and fits a groove cut in the quill. The main driving gear *F* has, integral with it, a taper shank which fits directly into the machine spindle and is fitted with a driving tang. A bronze bush *R*, of a diameter to suit the machine spindle, is fitted to the sleeve *O* to provide additional alignment to the head and to help steady it. The knurled plug shown at *S* is removed for filling the gear casing with oil.

Three-spindle Head

Fig. 4 shows a three-spindle head and also indicates the material used for the various parts together with the sizes of gears and numbers of teeth. These data should prove useful and provide an indication of the materials to be relied upon for drill-head work.

The drill head illustrated is designed to fit directly on to the spindle of a drilling machine of the type where no stationary quill is available on to which the drill head can be directly clamped. The centre driving shank is therefore clamped against the bottom of the machine spindle by means of the screwed collar shown and a split clamping ring, which is required in two pieces to permit assembly.

The drive is made positive by a key fitted through the driving shank on the drill head and the cotter slot in the machine spindle.

The head is designed as three main sections, consisting of the gear-case and the torque-arm bracket, between which is the thrust plate, these parts being made in aluminium in order to reduce weight and facilitate balancing the weight of the head on the machine.

To compensate for the extra torsional load on the machine spindle due to the combined torque of the three heavy drills, a reduction is arranged by a compound train of gears, laid out to ensure that the drill spindles rotate in the same direction as the machine spindle. This raises the speed of the drilling-machine spindle above that which would normally be used for the size of drill, if no drill head was being used. Therefore care must be taken to see that the feeds on the machine are low enough at the higher spindle speed to suit the work to be done, otherwise arrangements must be made to lower the feed range accordingly.

The thrust of each individual spindle is taken on the thrust races shown, which are adjusted by the two locknuts at the lower end of each drill spindle. The combined thrust of the three drills is taken by the race underneath the main spindle.

As the driving and suspending medium is rotating in the drill head, the torsional reaction has to be overcome and the head prevented from rotating as it is moved up and down during operation. This is achieved by clamping a bar to a convenient part of the machine and arranging the

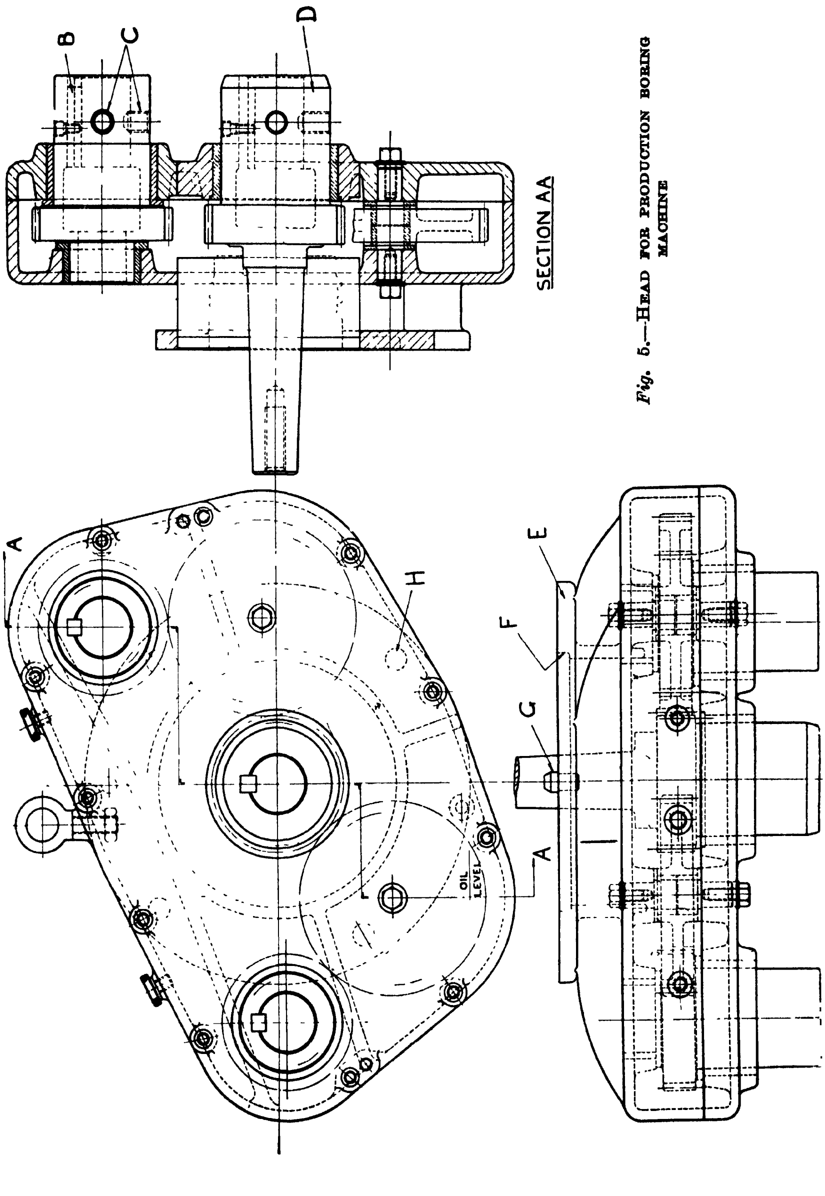


Fig. 5.—HEAD FOR PRODUCTION BORING MACHINE

two shoe plates fitted to the torque arm to slide one on either side of the bar. If very accurate alignment could be obtained between the guide bar and the machine spindle, a plain bronze bush in the arm would serve the same purpose as the two shoes in the illustration.

To prevent burrs scoring the bushes it is necessary that flats be machined on the spindles and clearance slots provided in the outer casing through which a drift can be applied.

Multi-head for Production Boring Machine

As previously mentioned, Fig. 5 shows a head designed for use on a production boring machine. The head has three spindles, each of which is arranged to drive a boring bar. Whilst the head remains attached to the machine it is necessary that the boring bars are detachable and are fed through the component after the latter has been located in the boring jig on the machine table. A driving key *B* and two locking screws *C* are fitted to each spindle, therefore, for driving and attaching the boring bar. The main driving spindle *D* has a taper shank on one end to fit the machine spindle, and is held in place by a drawbar through the hollow spindle of the boring machine. The gears and spindles are lubricated from a supply of oil in the bottom of the casing, the oil being splashed through the train of gears. The head is mounted to the machine by the flange *E* and is located by a register *F* and lined up by the dowel pin *G*, which fits a hole in the machine flange. The head is held in position by four bolts in the holes *H*.

It will have been noticed that in the examples which have been shown the spindles are fitted with plain bearings, the thrust only being taken on ball bearings. The spindles may be fitted with either plain or ball bearings at the discretion of the designer, but it is considered that unless the drills being used are exceptionally small, necessitating high spindle speeds, plain bearings are adequate.

Chapter XIII

MILLING FIXTURES

THE section on jig and fixture details has indicated many fundamentals which are incorporated in the design of milling fixtures. Complete concrete examples of such fixtures are therefore described in this section in the belief that a better guide towards correct design is conveyed than would be the case if further " scrap " views of part construction were continued. Any amplification of detail deemed essential or important is, where necessary, included in the explanation accompanying each example ; and whilst certain details of design may recur in several of the fixtures shown, reiteration has been avoided as much as possible.

The designs illustrated have been selected with the object of covering as comprehensive a range as possible of both usual and special applications. Attention has been given also to the kind of fixtures necessary to overcome operations presenting problems to the fixture designer, particularly where such problems are likely to occur in various branches of production engineering.

The Vice as a Milling Fixture

The simplest and probably the most universal type of milling fixture for general purposes is the vice. Expenditure on special milling fixtures can often be avoided by carefully thought out special vice jaws, so formed as to provide location and clamping, for either one or a series of operations on a component.

The component shown in Fig. 1 is taken as an example because all six milling operations are performed with the use of special jaws in a standard milling-machine vice. Before these milling operations the stamping has been brought to the correct width by grinding and the hole has been drilled and reamed.

Operation 1.—Locating on a peg from the hole, the component is held by a screw against a stop machined on one jaw. The vice is then tightened up in the usual manner and the three faces *A*, *B*, and *C* are machined with a gang of three cutters. It is necessary to hold the dimension between the faces to close limits, as *C* and *B* form alternate subsequent locations in conjunction with the limited hole. Provision for setting the cutters is arranged by the use of $\frac{1}{8}$-in. slip gauges from the faces *G*.

Operation 2.—Milling a slot lengthwise in the component is next carried out, and in this instance location is taken from the hole and one of the faces previously milled—shown at *B*. The depth and position of the slot are controlled by the slip gauge.

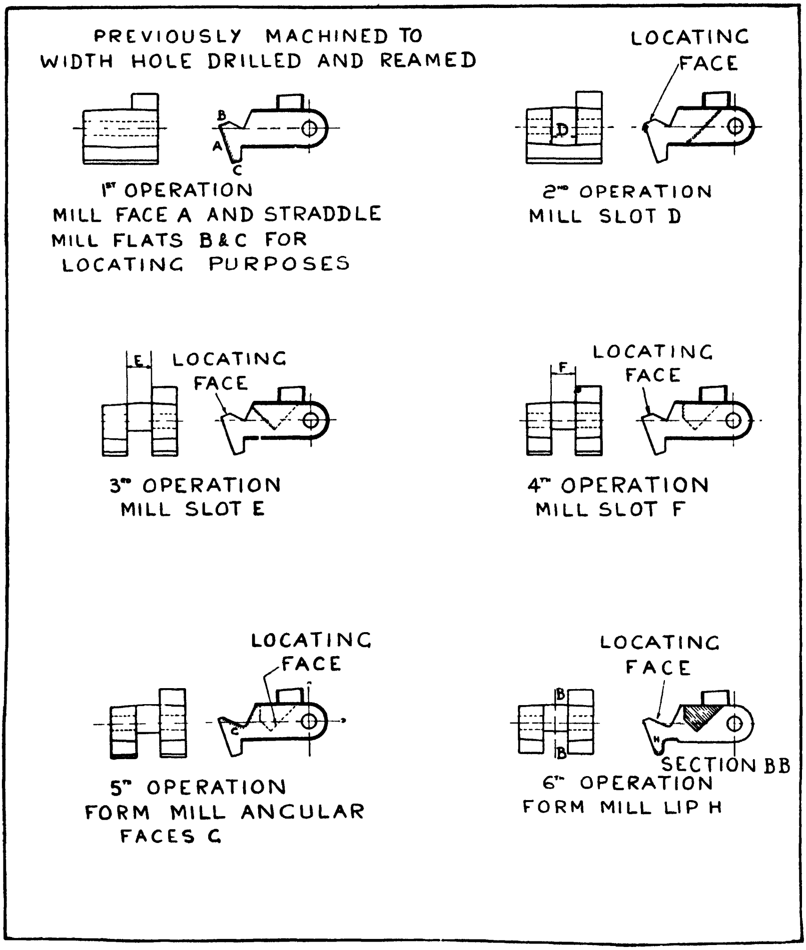


Fig. 1.—SEQUENCE OF SIX MILLING OPERATIONS USING VICE JAWS

Operations 3 *and* 4.—These are carried out in a similar manner to the last operation, with the exception that for convenience face *B* is now used for location. Care has to be taken also to see that the jaws are mounted in the vice so that the same face as before is adjacent to the fixed jaw, otherwise any variation in the width of the component as originally ground will be shown as a step where the slots join.

Operation 5.—Having completed the slot, the form-milling operation shown at *G*, Fig. 1, is carried out. The location for this operation is taken from the hole and the bottom of the previously milled slot. This point is chosen to ensure the correct relationship between the formed groove and the other machined faces. It also acts as a central support for the comparatively heavy cut. Face *B* is impracticable for location, and face *C* cannot be used satisfactorily because it is finally machined in the next operation. The cutter is set off the ground faces shown.

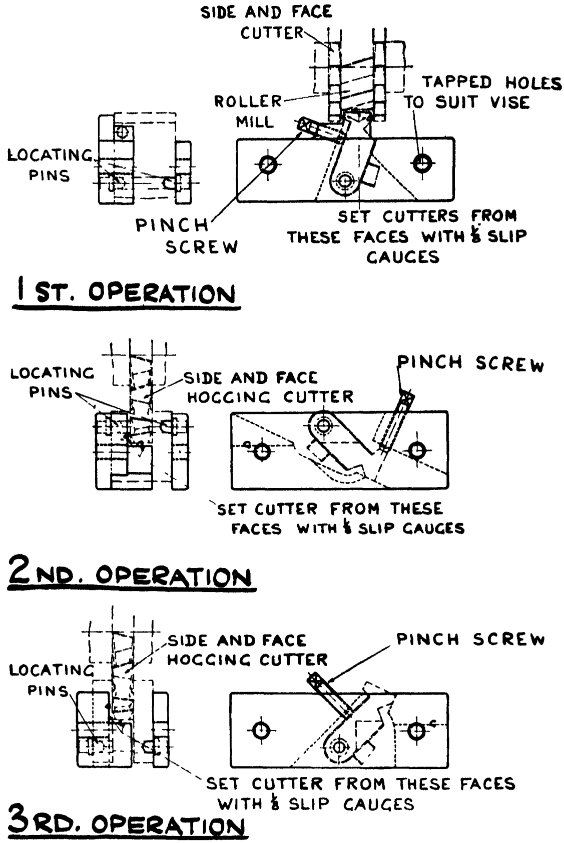


Fig. 2A.—LAYOUT OF VICE JAWS FOR SIX OPERATIONS ON THE COMPONENT SHOWN IN FIG. 1. SHOWING 1ST, 2ND, AND 3RD OPERATIONS

Operation 6.—This is necessary to ensure that the radius of the form machined in the previous operation and also that in the final operation are in correct relationship. Therefore the location for the final operation is the radius machined in operation 5. There being no tendency for the component to fall from its location in the last two operations before the vice is closed, a pinch screw is unnecessary.

Service Operation Milling Fixture

Due to a rapidly growing tendency for parts to be designed in a more complicated manner in an attempt to obtain lightness or compactness or both, components are frequently presented to the tooling department of

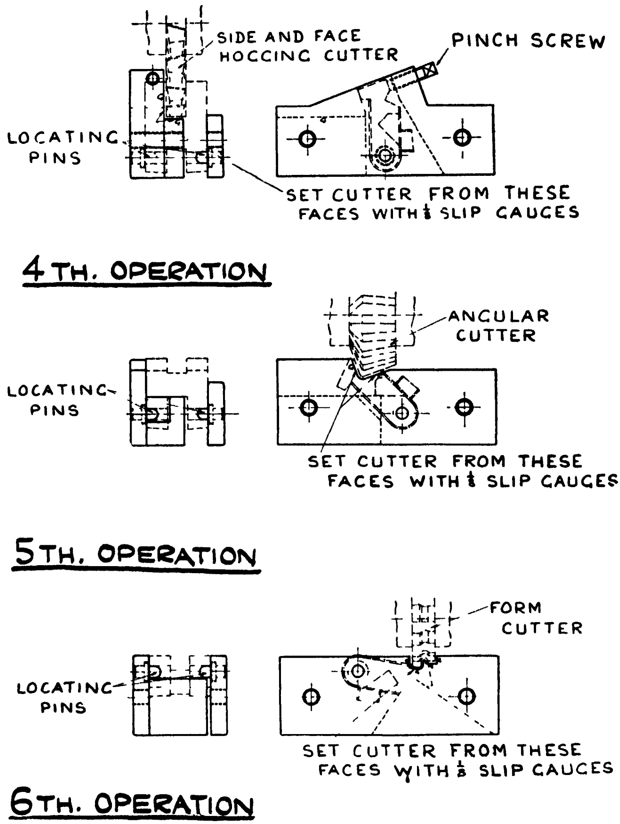


Fig. 2B.—Layout of vice jaws for six operations on the component shown in Fig. 1. Showing 4th, 5th, and 6th operations

such a shape that satisfactory locating and holding whilst machining would seem an almost insurmountable proposition. When such instances occur, thought must be given to the advisability of institutinga service operation.

The piece shown in Fig. 3, apart from the intricate shape, is subject to distortion when cooling and handling after being stamped, and also to small variation in thickness, due to the amount of metal placed between the dies and how close the dies have been brought together during the stamping operation. One face *A* of the long boss was chosen for the service operation ; this to be milled full to the extent of $\frac{1}{16}$ in. above the drawing dimensions. This face must be machined in such relationship with the rest of the stamping that when the remainder of the machining is completed the faces required are not out of position with the unmachined portions of the stamping. An examination of the stamping will reveal that such a condition might arise when machining the width *B* of the fork, there being only $\frac{1}{32}$ in. each side over the width of the stamping at *C*. It is essential, therefore, when arranging the fixture for machining the datum face, that location is taken from positions on the stamping where no subsequent machining is required.

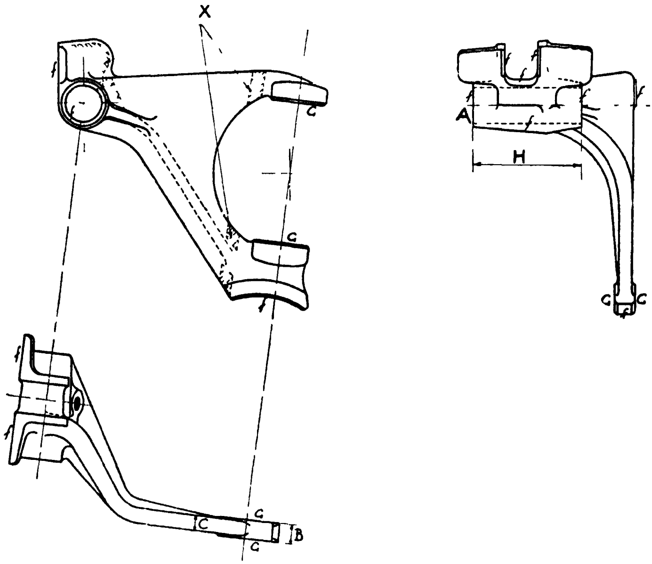


Fig. 3.—LOCATING A STAMPING FOR A SERVICE MILLING OPERATION

The three spots *X* (shown etched) were chosen, therefore, because they are as widely spaced as is possible and are also accessible; furthermore, they are adjacent to faces subsequently machined.

On the fixture, Fig. 4, the underside of the bars *D* and *E* provide location faces for the three positions chosen and are bolted at the correct heights on the pins *F* and *G*. The two clamp screws when raised under the component hold it in against the location bars in a position which should make compensation for all except unusual stamping irregularities which, should they occur, are readily discernible in the fixture and the stamping can be thrown aside without more ado. The pin F_1 is raised to provide a setting gauge for the milling cutter.

After milling, a flat face is available, forming a datum from which, it may be expected, the subsequent operations will be satisfactory. The face is used primarily as a seating on which the long boss can be clamped for drilling and reaming. As a light cut only is needed to machine the

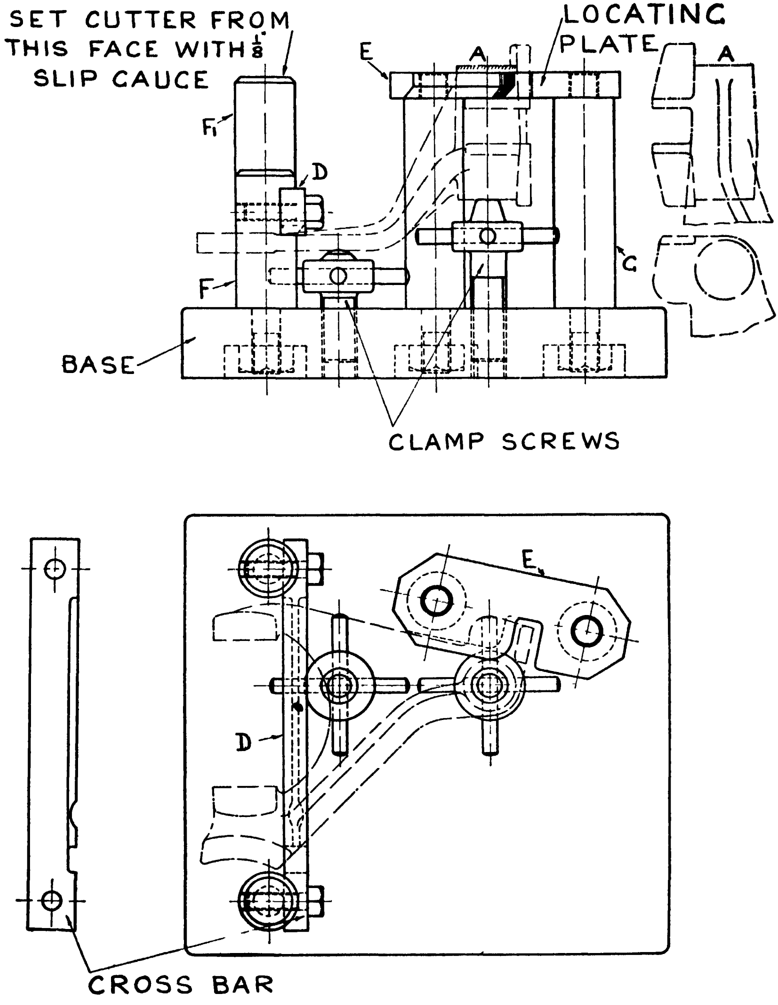


Fig. 4.—FIXTURE USED FOR A SERVICE MILLING OPERATION

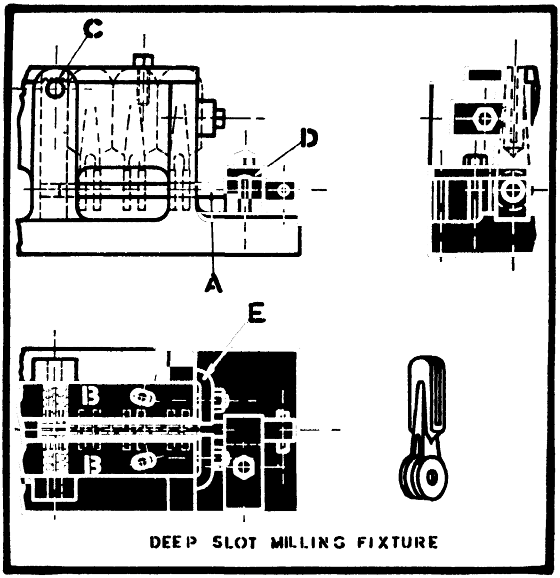


Fig. 5.—DEEP-SLOT MILLING FIXTURE

datum face the clamping shown is adequate. The $\frac{1}{16}$-in. surplus on the datum face is removed in a convenient subsequent operation.

Deep-slot Milling Fixture

This fixture—Fig. 5—is shown because on the surface it seems to be an example of what not to do in design. There are loose pieces and several clamps to manipulate, and it might have been thought preferable to pass it over, except that it serves to prove that many of the rules laid down in an earlier chapter may, on occasion, be broken without regret. This fixture has proved very satisfactory in service, neither trouble nor scrap resulting from its use, whereas the type of operation on which it is used had previously given difficulty. It is for milling deep and narrow slots, in this instance about 4 in. deep by $\frac{5}{16}$ in. wide.

The circular bosses on the component are first straddle milled and drilled. The components are then assembled three together on each of the two pins (shown at *A*) which fit the drilled holes, and these pins are placed in the fixture from either end. (*Note.*—Only one half of the fixture is shown.) The holes are thus located in line. The walls of the components are lined up by a parallel motion obtained by two plates (shown at *B*) on the top of the fixture which operate through a pinion engaging with rack teeth cut in these plates. Elongated slots at either end of each plate act as cams for opening and closing the two plates. In practice it is found that the variation in the stampings is small enough to permit one plate being set to suit the batch and locked in position, the opposite plate only being operated when setting. This is done by a key with a pinion cut on the end to mesh with the rack cut in the plates.

The components which are machined on the edges are then clamped

endwise by the clamps *E*, and the block *D* locating the pin is clamped to the base.

Two fixtures operate side by side, and in spite of the apparent large amount of spannering to be done, the fixtures are quickly loaded in practice and, because of the depth of cut, the proportion of loading time to cutting time is quite small.

Fork-end Milling Fixture

On this example both the slot and the side faces have to be milled, and the shape of the stamping renders it difficult to string the components tandemwise as was possible with the previous example. To reduce cutting time, therefore, the component is held (lying parallel with the table) in the fixture, and the pieces fed into the milling cutter on the centre line of the arbor, the cutting action being downwards whenever possible.

When warranted by the quantities, two fixtures may be placed side by side and additional cutters mounted on the arbor to accommodate the work on two components. For very large outputs fixtures can be mounted at either end of an indexing table, so that loading takes place on one end whilst the pieces are being machined at the opposite end. This is to be preferred to the practice of mounting fixtures at either end of the table and traversing in both directions alternately towards the cutter, cutting upwards in one direction and downwards in the other. When loading by this arrangement the operator must get his hands between the fixture and the cutter—a dangerous practice.

The body of this fixture is cast iron, and it will be seen (Fig. 6) that the section of the casting is uniform or approximately equal thickness. Whenever possible, castings should be so designed, as this prevents distortion and blowholes through unequal cooling. Milling fixtures need rigidity—the two ribs *K*, therefore, are curved, as shown, so providing greater strength than if made straight, as the dotted line *L*.

The bottom block *B* is formed to suit the shape of the stamping, the front portion cut away, forming two jaws to clear the milling cutters, whilst the rear is shaped as a vee block.

The clamping block is similarly formed, except that the vee is not required, the clamping face being flat. A shoulder is, however, formed on the end to function as a rough endwise location. If this shoulder had been arranged on the bottom block it would have been an additional swarf trap.

The clamping block is floating to compensate stamping irregularities.

The clamping screw is made spherical ended and clamps through the bottom of the tee slot *C*, the shoulders of which are used for raising the clamping block, which is positioned endways by the pins *D*. The bush *E*, which is a part subject to wear, has been provided to avoid the necessity for replacement of the top block *F*. The clamping thrust is taken

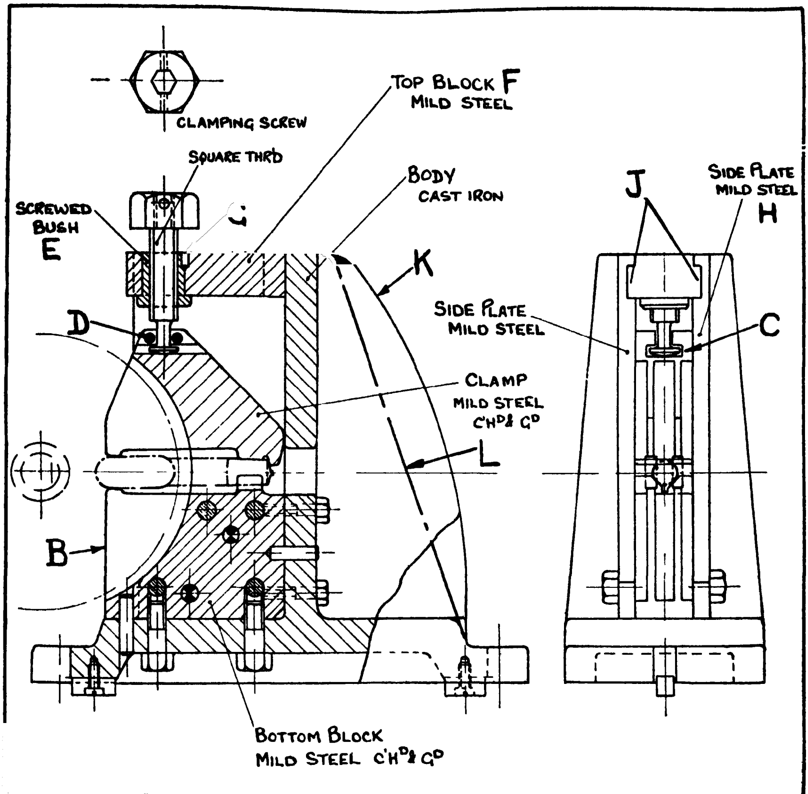


Fig. 6.—FIXTURE FOR SLOTTING AND STRADDLE MILLING

through the bush, and a shoulder is therefore provided at the bottom for this purpose. The bush is prevented from rotating by the dowel *G*. The fixture is stiffened and the clamping block lined up by the side plates *H*, into which the top block *F* is fitted, this being positioned by the tongues and grooves *J*, which take the clamping thrust.

Slot-milling Fixture with Toggle Clamping

The fixture shown in Fig. 7 is used on a slot-milling machine and is for milling a slot in both sides of the fork on the component, the slot being formed roughly in the stamping operation. The fork is previously straddle milled and the centre slot machined on a fixture similar to that shown in

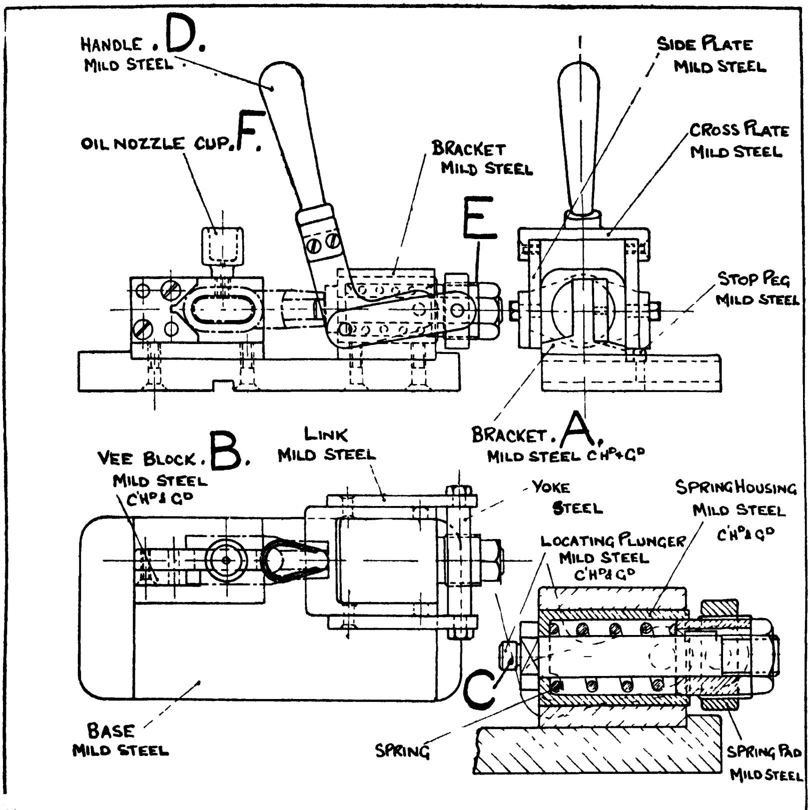


Fig. 7.—SLOT-MILLING FIXTURE WITH TOGGLE CLAMPING

Fig. 6. The component is located on the bracket *A*, which fits the centre slot, and is lined up by the vee block *B* at one end and a plunger *C* at the other which carries a spigot locating in a previously drilled hole.

A toggle action is used for clamping, this causing the plunger *C* to be spring loaded on to the component and providing sufficient clamping load for this operation. The toggles are operated by the hand lever *D* and may be adjusted at *E*. The oil-nozzle cup shown at *F* has inserted in it a flexible pipe supplying cutting oil from a pump on the machine. The oil, being delivered between the two sides of the fork, washes the swarf away from the cutter as it flows through the slots being milled.

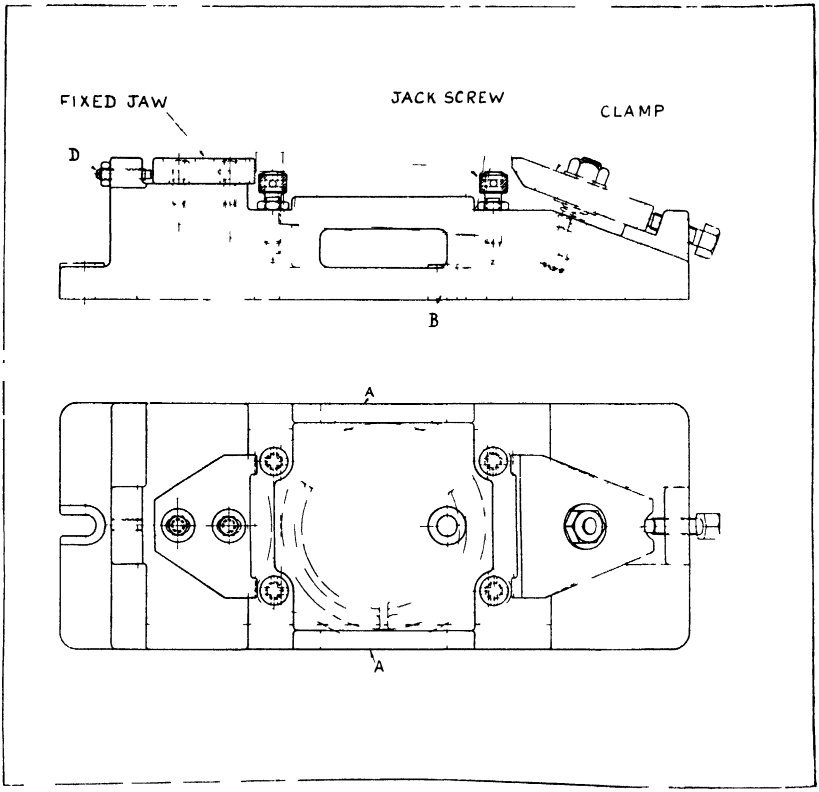


Fig. 8.—EDGE CLAMPING MILLING FIXTURE

Edge-clamping Milling Fixture

The type of fixture illustrated in Fig. 8 is required when, owing to the shape of the component, direct downward clamping is not possible. The operation to be performed is that of milling the joint face on a vertical milling machine. The component is laid in the fixture on four jack screws, three of which remain set, the fourth one being raised or lowered to suit each component.

Whilst three fixed positions for location would have been better, the shape of the component is such that this is not possible, because support is required in the fourth position and, furthermore, if three only were used, the component would be out of balance and so would not lie on the three points but have a tendency to be clamped out of position. The

component depicted, being a stamping, is rigid enough, so that it is not distorted or closed in by the clamping action.

When frail parts have to be clamped in this manner, an adjustable expanding device should, where the shape of the component permits, be assembled into a piece before placing it in the fixture. The clamp is arranged at an angle of approximately 20° to 25° and its action is such that, whilst preventing the component from rising under the cut, it at the same time thrusts the work against the serrated jaw on the opposite side.

Adjustment is provided for the serrated jaw so that it will accommodate variations should they occur in batches of components, but remains set throughout each batch. This adjustment is required so that the clamp on the opposite side may operate in the centre of the flange on the work, instead of either standing "proud" of the face to be milled or falling below the flange due to casting variations. Two clamping points are provided on the clamp, and so that these both come into operation the clamp is arranged to float on the ball-headed adjustable screw at its opposite end. To prevent any tendency for the fixture to break across the centre, the webs *A* bridge the opposite ends. No tenons for aligning the fixture are required in this instance.

There are two places provided for bolting the fixture to the table, one of which is at *B* near the centre of the fixture. This has been done so that the clamping-down bolt does not interfere with the adjustable screw *C*, as would be the case if the clamping arrangements had been made at either end of the fixture.

The fixed-end jaw has been provided with screws, the heads of which are countersunk so that no part of the fixture stands above the face to be milled, so interfering with and possibly damaging the cutters. The screw *D* behind the fixed jaw takes the clamping load off the two countersunk screws and makes the position of the jaw solid and positive.

Sighting Plate, First-operation Milling Fixture

When designing first-operation milling fixtures for castings of irregular shape on which there are facings widely distributed, it is essential that precautions are taken to ensure that when subsequent operations are completed, the work done is in proper relationship to the surrounding material, i.e. holes are drilled or bored central with bosses and machined faces do not leave flanges thick on one side and thin on the opposite side, or run into unmachined parts of the casting—a frequent and unsightly fault. The casting shown as dot-and-dash line in the fixture, Fig. 9, is such a piece and is not compact enough to be controlled by the "spotting points" referred to in "The Jig and Tool Department." Therefore the three faces adjacent to the sighting plates *C*, *D*, and *E* have been chosen because they are positions as widely distributed as possible; furthermore, when machining is completed there is a relatively small

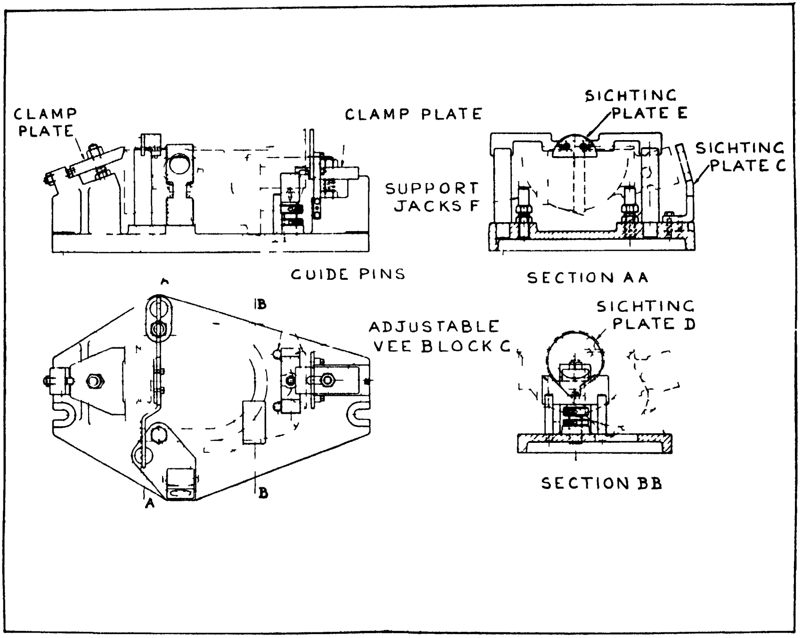


Fig. 9.—FIRST-OPERATION MILLING FIXTURE WITH SIGHTING ARRANGEMENTS

amount of material remaining and the machining must therefore be centralised.

Before clamping, the casting is placed on the two jacks *F* and the adjustable vee block *G*. The locating vee serves the purpose of centralising the material beneath the ball-race boss at that end and is raised to bring the end face to match up with the sighting face *D*. At the opposite end of the fixture the supporting jacks *F* are raised or lowered to bring the material forming the face of the boss into a position to coincide with the sighting plate *E*, and at the same time adjustment is made between the supporting jacks *F* to bring the elongated boss at the side into its correct relationship with the sighting plate *C*. The sighting plate *E* would be in the way of the milling cutters when milling the top joint face ; it is therefore made removable and located for height and position by two raised pins. The clamping is orthodox and follows on the lines of some of the methods previously described.

With the above precautions taken, it can be assured that when providing jigs or fixtures for subsequent operations, at the same time locating from the joint face milled in this operation, satisfactory results will be obtained.

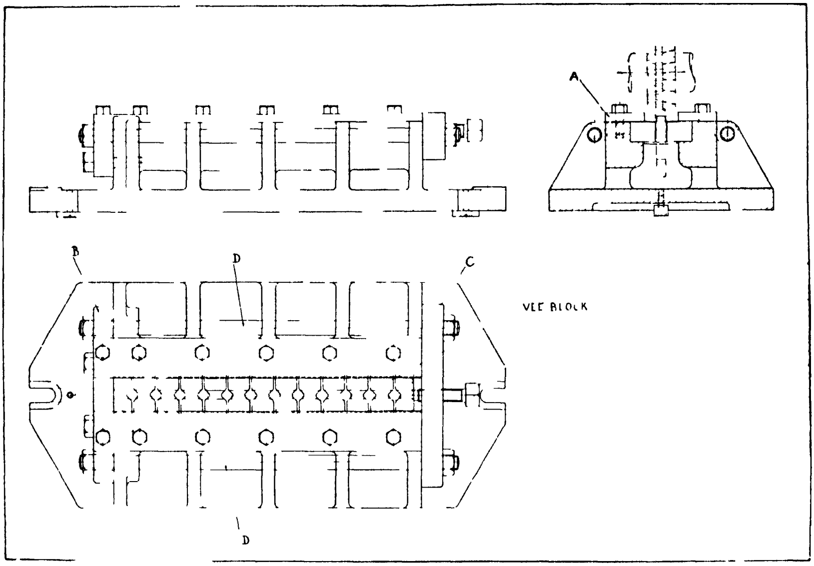


Fig. 10.— Standard string-milling fixture

Standard String-milling Fixture

Component parts of many varying shapes and sizes can be string-milled, that is, the components are arranged in the fixture in line or in tandem and the cutter or cutters passed along the row. The length of the row depends upon the size of the milling machine or its accuracy over a given length of traverse. The type of fixture shown (Fig. 10) is used for milling forms on the heads of components having a shank. The pieces are held between hardened and ground vee blocks, which are free to slide in a slot cut in the body of the fixture. The blocks are prevented from rising by the top plates *A*, which are also hardened and ground on the underside. This type of fixture comes within the category known as standard fixtures, because, by designing vee blocks to suit various components, many different pieces can be accommodated.

When using such a fixture it is essential that adequate arrangements are made for the removal and clearing of the swarf. The " windows " cored in the sides of the body of the fixture are provided so that swarf falling between the vee blocks can be pushed or washed clear. The clamping thrust falls on the two end plates *B* and *C* and is transferred to the bolts *D*, which are thereby placed in tension. No strain in consequence occurs in the casting, as would be the case if the end plates *C* were screwed or bolted on the ends of the body of the fixture. The base of the fixture is relieved to reduce the area seating on the machine table.

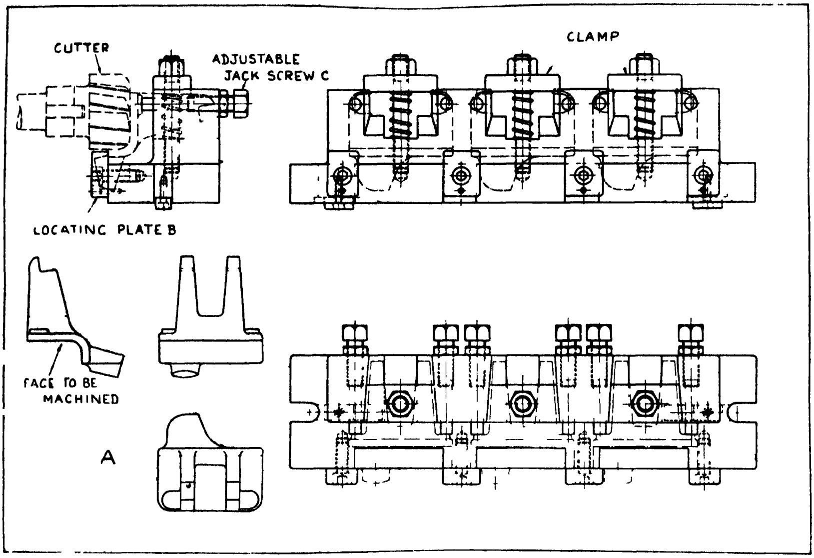


Fig. 11.—STRING FIXTURE FOR FACE MILLING ON HORIZONTAL MACHINE

No fixture should be relieved underneath the position where it is to be clamped to the machine table, otherwise distortion is set up in the fixture. Clamping can, of course, be arranged by a cam action instead of a screw, if desired.

String Fixture for Horizontal Machine

The fixture illustrated in Fig. 11 is representative of a simple milling fixture for use on the horizontal-type milling machine using a stub arbor and face-milling cutter. The stamping to be machined is shown at *A*. The operation to be performed is the first and is that of milling the right-angled attachment face. The simple nature of the fixture is such that the cost of making a pattern for a casting can be avoided by machining the body from a bar of mild steel. The little extra machining required is worth while, as pattern-making and foundry delay is avoided.

The component is located in slots cut at an angle through the body of the fixture, the angle arranged to suit the component, but the slot cut $\frac{1}{8}$ in. full in width to allow for stamping irregularities. The locating plates *B* bolted to the front of the fixture serve to line up the stamping. The result of the clamping action is twofold : the stamping is held downwards, and because the component is sitting on the angled face on the bottom of the slots it moves forward against the locating plates *B*, and is in consequence lined up longitudinally.

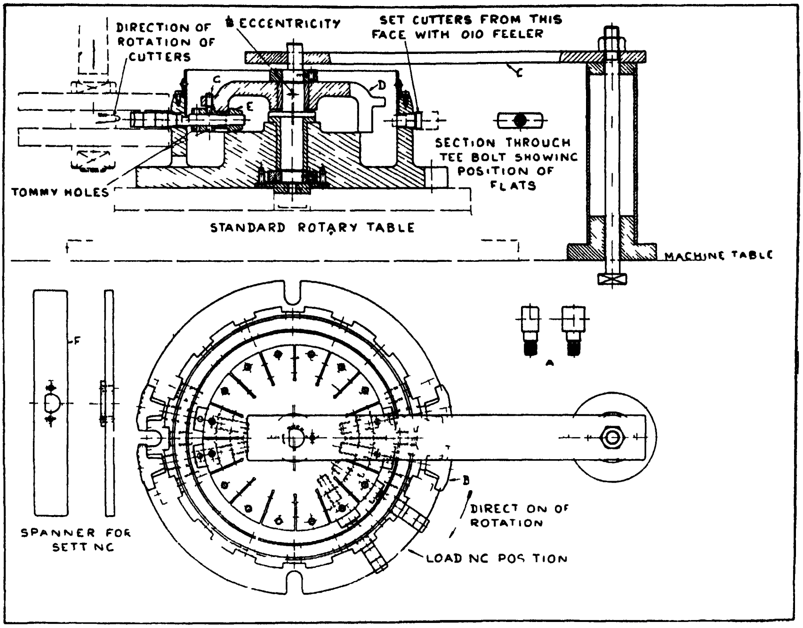


Fig. 12.—Continuous rotary milling fixture

The adjustable jack screw *C* serves to support the extreme ends of the component whilst machining and, when loading, are slackened back until the top clamps have forced the component into its correct position. The component is loaded from the cutter side of the fixture, this being done by slackening off the top clamp. The clamp is raised by the springs assembled over the clamping studs, and the component can be inserted readily without removing either the nut or the clamp. Such a fixture must be parallel on the machine table, and for this purpose tenons are fitted in the base of the fixture for alignment purposes.

Continuous Rotary Milling Fixture

The ideal arrangement for milling is to traverse past previously set cutters a continuous stream of components at the maximum feed consistent with the nature of the material, each one being correctly located and clamped, and the fixture designed to give as much rigidity as possible and arranged so that loading and unloading may take place whilst the cut is in progress Because cutting time for this type of fixture would usually be less than that taken for clamping and unclamping by manual

means, some form of automatic clamping should be devised. The rotary fixture shown in Fig. 12 is designed to satisfy, as closely as possible, this condition.

The operation is that of straddle milling the sides of an eyepiece *A* parallel and central to the previously turned stem. The components are located in equally spaced holes disposed radially in the main body of the fixture and positioned by slots machined to the correct width and central with the holes. Clamping is by the action of the tee-headed bolts, *B*. The clamping action is made automatic by the revolution of the fixture, which is mounted on the standard rotary table forming part of the equipment of most vertical milling machines.

The whole fixture rotates around the central pin, which is stationary and anchored to the machine table by the torque arm *C*. That portion of the pin locating the bell-shaped hub *D* is $\frac{1}{16}$ in. eccentric to that located in the fixture body ; in consequence the hub and the fixture body rotate about different centres $\frac{1}{16}$ in. apart. This causes the heads of the bolts (when correctly set) to be $\frac{1}{8}$ in. nearer to the centre of the body of the fixture on one side than those diametrically opposite. This movement is used for clamping and releasing.

Adjustment for each tee bolt is made by the use of the screwed bush shown at *E*. When first setting, the fixture is loaded with components and the centre pin rotated by using a special spanner *F*. At the position when each bolt in turn is drawn towards the centre to the maximum amount, the shouldered sleeve screwed to the tee bolt is turned on the bolt with a tommy-bar until sufficient clamping load is developed by the spring produced by the eccentric movement of the hub. The dowel screw *G* is then inserted. The bushes are not a tight fit in the slots, sufficient clearance being provided to allow for slight angular movement, due to the eccentric motion.

The hub is strained on one side during rotation, and is therefore split into sections, so that the tension set up by one component does not influence the clamping effect of the adjacent bolt, making allowance for small variations in the length of the clamped portion of the component. In consequence, this part should be made from heat-treated steel, to maintain elasticity over long periods.

In order that the initial setting may not be lost when the tee bolts are turned for loading purposes, a groove is machined in the stem of the bolt, so restricting the angular movement to 90°. The splash guard for the cutting compound is designed to interfere with the full diameter of the bolt and prevents further movement ; the operator cannot then inadvertently turn the bolts out of adjustment when loading. The angular position of the centre eccentric pin determines which is the tight and the loading side of the fixture ; therefore the *D*-shaped shank is machined in relation to the eccentric ; in consequence, when the arm is anchored to the table the components clamped the tightest are continually

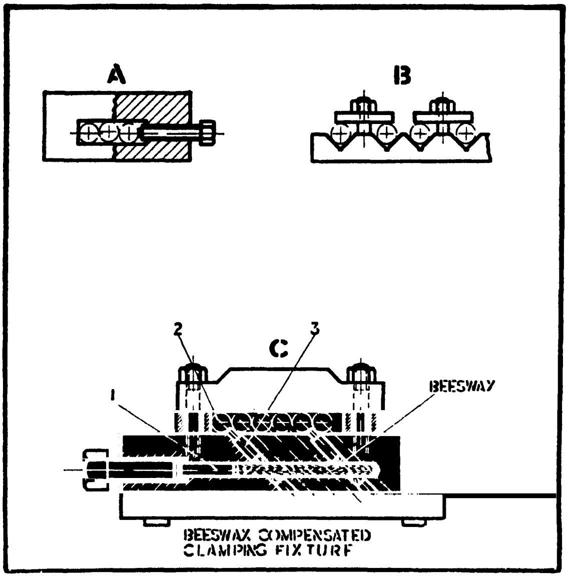


Fig. 13.—MILLING FIXTURE WITH FLUID CLAMPING

offered to the cutters.

Fluid - compensated Clamping Fixture

This has proved to be an excellent method of overcoming an apparently simple operation, but is nevertheless one which has caused, and is no doubt still causing, trouble in many works.

Suppose a flat or a slot has to be milled in a round bar, and there are large quantities to machine. The bars are all turned or ground to within a specified limit, and the flat or slot has to be to an accurate depth. Now, referring to Fig. 13, it is possible to slide these in a gap and screw up on the ends (as shown at *A*), in which case some will be forced to the top and some to the bottom of the slot, giving errors on the depth of the flat equal to the differences in diameter of the shafts, due to the tolerance. Further, there is difficulty in preventing the bars turning under the cut. Alternatively, they can be dropped in vees with clamps between (shown at *B*), and so increase the time for the work, because the cutter has to cross the gap.

A better method will be found in the use of the fluid-clamping fixture (shown at *C*), the clamping medium of which is beeswax. The principle used in this fixture can be arranged to suit other components, and the description is of its most simple application only.

The long hole in front of the clamping-screw plunger (item 1) and also that part of the holes not filled by the clamping pin beneath each component (item 2) are filled with beeswax. A few turns of the clamping screw creates a pressure on each of the pins (item 3), at the same time compensating the clamping of each component. This is a particularly trouble-free arrangement, and certainly holds the work more uniformly than tightening against each piece individually.

The components are all forced, it will be noticed, in one direction against the top plate, which is hardened and ground ; thus the depth of the slot is controlled. To remove the components, after releasing the pressure, the top plate is slacked off. This allows space to assemble a row of work. A fixture similar to the one described has been in use for four years without replacing the beeswax.

Simple Hydrostatics

The following reference to simple hydrostatics may be applied when designing a fixture on these lines. The pressure created in the system by the screw is directly proportional to the load applied, but inversely proportional to the area of the ram. The load on each pin clamping the work is directly proportional to its area for a given pressure.

Should the components vary in thickness, ensure that there is sufficient traverse in either direction on the clamping screw, and when choosing the ratio of the diameters, remember that the idle linear movement of the ram is equal to the sum of the volumetric displacement of all the pins, divided by the area of the ram. On the arrangement shown, assuming 3 tons on the screw, using a 20-in. wrench, a pressure of 9·75 tons per square inch is obtained, resulting in a load on each pin of 1·18 tons at 80 per cent. efficiency in the unit.

Loads Transmitted by various Diameters of Screws

The following are the actual loads transmitted by various diameters of screws using the standard spanner. The tests were made on a Buckton machine and are the average resulting from a comfortable pull of two individuals weighing 9 stone and 11 stone respectively. The apparent disparity in some of the figures will serve as a warning to designers to the effect that what is expected may not always materialise.

	Length of Wrench In.	*Tons (Average)*
¼-in. B.S.F. Bolt	4	1·20
¼-in. Whitworth Bolt	4	·96
$\frac{5}{16}$-in. B.S.F. Bolt	4	·91
$\frac{5}{16}$-in. Whitworth Bolt	4	·86
⅜ in B.S.F. Bolt	5¾	1·5
⅜-in. Whitworth Bolt	5¾	1·46
$\frac{7}{16}$-in. B.S.F. Bolt	5¾	1·35
$\frac{7}{16}$-in. Whitworth Bolt	8	2·3
½-in. B.S.F. Bolt	8	2·1
½-in. Whitworth Bolt	8	1·82
⅝-in. B.S.F. Bolt	9	2·8
⅝-in. Whitworth Bolt	9	2·8
¾-in. B.S.F. Bolt	9	2·4
¾-in. Whitworth Bolt	11	2·1
⅞-in. B.S.F. Bolt	12	2·7
⅞-in. Whitworth Bolt	12	2·65
1-in. B.S.F. Bolt	16 (two-handed)	5·8

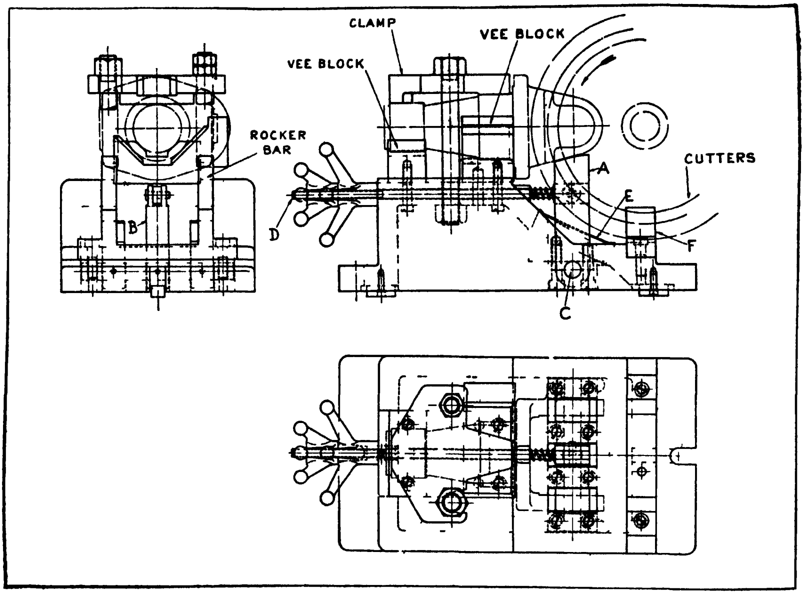


Fig. 14.—GANG-MILLING FIXTURE

Gang-milling Fixtures

The gang-milling fixture illustrated in Fig. 14 is designed for the operation of milling four faces on the jaws of a yoke, the shank of the component having been previously turned. The "in-feed" method of cutting is used; that is, the cutters traverse into the jaw on the centre line of the shank.

An alternative method would be that of holding the component in a vertical position and traversing through instead of into the jaws. Such a method is essential when straight lines must be left by the milling cutters at the bottom of their cut, but when it is possible to leave these surfaces curved as they would be formed by the periphery of the cutters, then the advantage of the "in-feed" method is that a shorter traverse is required to complete the operation.

The previously turned stem is located and clamped in two hardened and ground steel vee blocks, the larger vee also taking the thrust of the cut on the shoulder at the end of the turned portion of the component.

Angular location of the jaws is taken from their unmachined edges, which are squared up by two cam-faced levers *A*, between which is disposed the operating lever *B*. These are synchronised and hinged on cross-pin *C*.

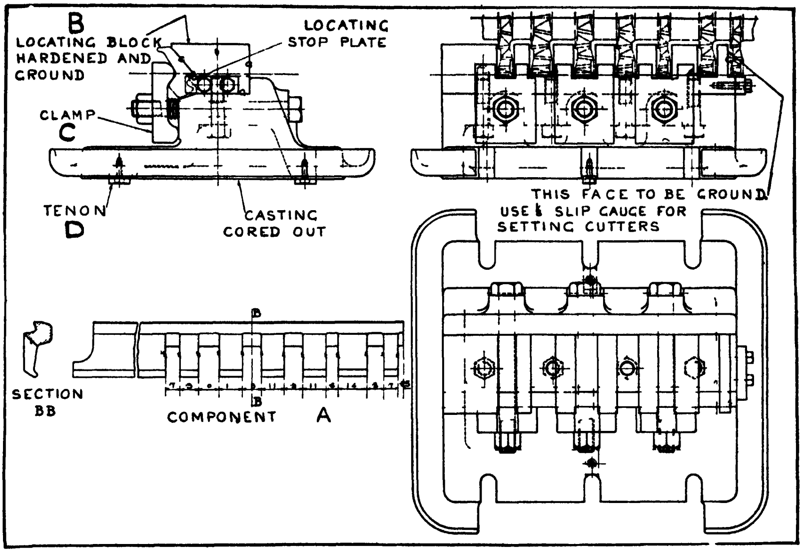


Fig. 15.—FIXTURE FOR GANG-MILLING SLOTS

Attached to the operating lever is a screwed drawbar *D*, by means of which the cam levers are drawn underneath the work, obtaining correct location and also acting as additional support against the downward thrust of the cutters.

To prevent chips from falling into and clogging the slots cut in the fixture in which the three levers operate, a close-fitting guard *E*, which moves with the levers, is provided, so sealing the openings.

The correct height and spacing of the cutters is taken from the setting block *F*. In order to facilitate loading, the clamp is arranged to swivel approximately half a turn by slotting the hole through which the clamping stud operates. The stud on the opposite side serves as a swivel pin only, and over it is fitted a spring to prevent the clamp from falling.

Fixture for Gang-milling Slots

The amount of milling being done at one time on the component shown at *A* (Fig. 15) presents, at the first glance, a holding problem of none too simple a nature, in so far that, as seven milling cutters are passed through the component together, there remains on the component itself a relatively small area for clamping and locating, which, in view of the amount of work involved, must be of a particularly rigid character.

The fixture used is, nevertheless, of quite a simple design. A locating block *B* is bolted across the top of the fixture, seating on a face on the fixture body and butting against a shoulder. The front face of the

locating block is casehardened and ground and is vee'd to the same angle as the component. Into this the component is clamped, the vee being milled away to allow a path for the cutters ; the clearance slots are $\frac{1}{8}$ in. wider than the milling cutters themselves, so that there is no tendency for the cutters to rub on the sides of the slots. The three clamps *C* are cut away in like manner ; the clamping faces are formed to suit the component and the heel of the clamp is radiused. The clamping bolts are passed right through the fixture.

This should be done wherever possible, because by so doing the fixture is kept in compression, there being less likelihood of breakage of the cast iron than would be the case if, instead of bolts, studs were used and all the clamping effort in consequence transmitted to the threads. The shoulder against which the bolt heads lie prevents the bolts turning when tightening the nuts.

Because the fixture in this case is slightly wider than the table on the milling machine, a tray has been cast integral so that cutting lubricant and swarf can be guided and washed on to the machine table, preventing the mess which can so often be observed around milling machines. The fixture is securely bolted to the table—a necessary precaution on such heavy cutting—by three clamping slots cast on either end of the fixture, these being of a pitch to suit the tenon slots on the machine table. The fixture is maintained and set in alignment with the table by the tongues *D* in the base.

To reduce hammering on the machine and horse-power requirements for such a cut, milling cutters are provided with helical teeth, and in order to balance the thrust these are staggered alternately right and left hand. Setting the cutters is accomplished by means of a 2-mm. slip gauge off the end of the hardened vee block at *G*, this face being ground to give the correct dimension from the stop plate.

Indexing Fixtures

When engaged on any tooling programme, consideration should be given to the possibility of utilising one fixture for several operations, not necessarily on one component, but on different parts. This is only possible when quantities are such that one operation does not occupy the machine for the whole of the time available, so permitting the operations to be machined consecutively or in smaller batches, in order that some of each are available when required.

Fig. 16 shows such an example. On either side of the fixture are depicted the two components accommodated in this instance, on one of which the boss *A* has to be straddle milled, whilst on the other two of the internal faces at *B* have to be milled. The reason for making the fixture index is that whilst a component is being machined on the one side, loading and unloading may be done on the other and time thereby saved. On the two operations in question the cutter settings differ ; the work

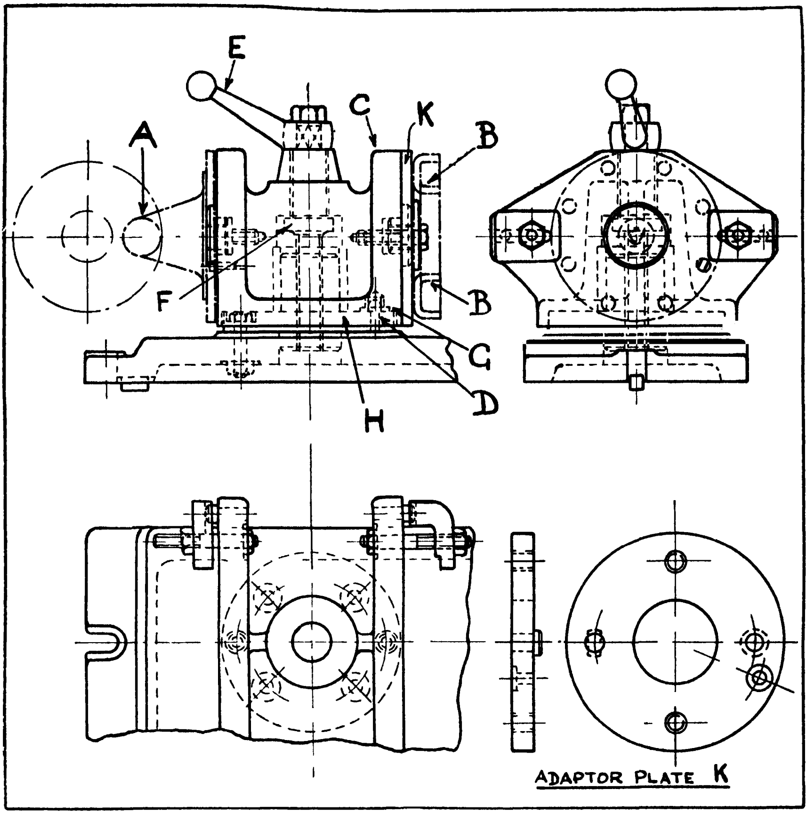


Fig. 16.—Indexing fixture adaptable for two components

pieces, therefore, cannot be mixed, either one type or the other being machined in batches. The base of the fixture remains bolted to the machine table whilst the revolving centre piece is raised off the locating pin *D* by unscrewing the clamping lever *E*. The collar *F* on the centre screw is provided to effect this movement. Two hardened and ground bushes *G* are fitted in the base of the casting *C*; these when pushed in turn over the pin *D*, due to the clamp being tightened, establish the two positions required for machining.

Clamping is done by the lever *E* through the screw on the lower portion of the centre pin and the tapped hole in the spigot *H*, which is located in and bolted to the base. A hardened and ground bush is pressed on to the

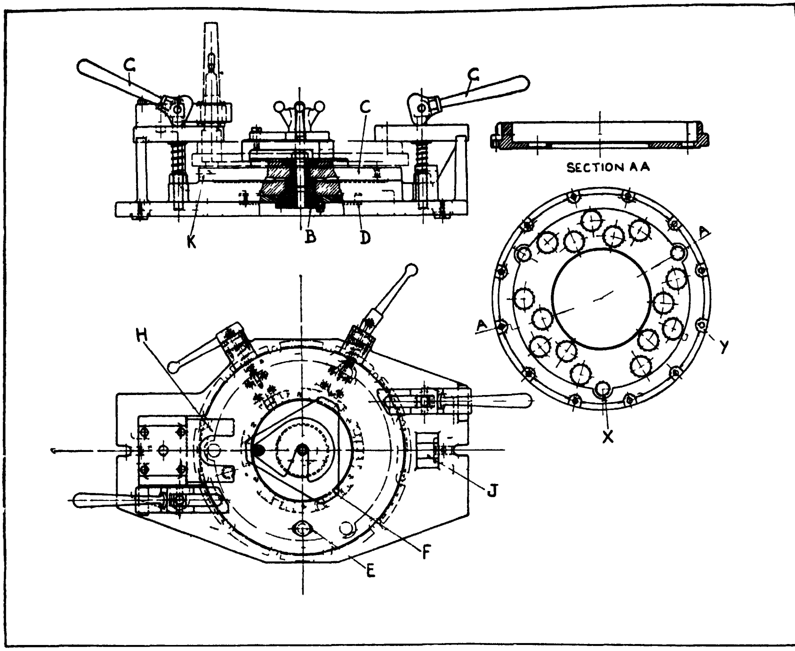


Fig. 17.—Double purpose indexing fixture

casting *C*, and this revolves on the hardened and ground centre pin, thereby maintaining accurate alignment.

To keep particles of swarf from interfering with satisfactory indexing, the base of the casting is counterbored to shroud the flange of the spigot *H*.

When machining the bosses shown at *A*, the component is located by a spigot and a locating pin fitted directly to the casting *C*.

For the operation shown at *B*, two adaptor plates *K* are used, one on each side of the fixture These plates are provided with pins to locate the component and are themselves centralised on casting *C* by the spigot and locating pin used for operation *A*.

The indexing milling fixture shown at Fig. 17 is designed to accommodate two operations, namely the milling of three semicircular recesses, as at *X*, and the twelve gaps, as at *Y*. The fixture is bored for a central spigot *B*, to which are attached a circular table *C* and an indexing plate *D*.

The component is located on a spigot which is part of, and integral with the revolving table and, as the holes shown in the component are already drilled and reamed, it is essential that they are in accurate

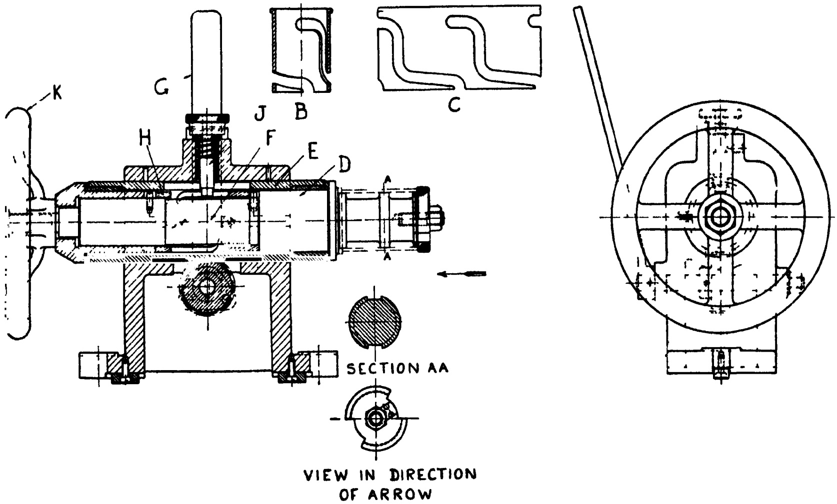


Fig. 18.—FIXTURE FOR MILLING SPIRAL SLOTS

relationship with these slots in the indexing plates. The locating pin *E*, therefore, serves this purpose.

The component is clamped to the revolving table by the three-point clamp *F* positioned centrally and readily removed for loading purposes when the hinged and slotted washer is moved to one side. After each index, the component, together with the revolving parts including the indexing plate, is clamped solid by two clamps *G*, cam-operated. These prevent any tendency for the moving parts to creep and become out of unison under the action of the milling cutter. End mills are used for each of the two operations. These are ground to the correct diameter to suit the two widths of slot.

The larger of the two cutters, because of the area in contact, will cut more steadily if a supporting medium is arranged, and the plate *H* serves this purpose. The jaws of the plate guide a roller fitted over the socket into which the end mill is inserted. The jaws serve also to position and control the depth of cut. The slot machined at *J* is used to position the small cutter.

Preventing Errors when Indexing

To prevent errors when indexing, the index mechanism is arranged as follows. The plungers which position the index plate are staggered so that one is fitted on a higher plane than the other. In the index plate a series of slots are cut, spaced correctly to suit the slots to be milled and of sufficient number to suit both operations on the component. The plungers

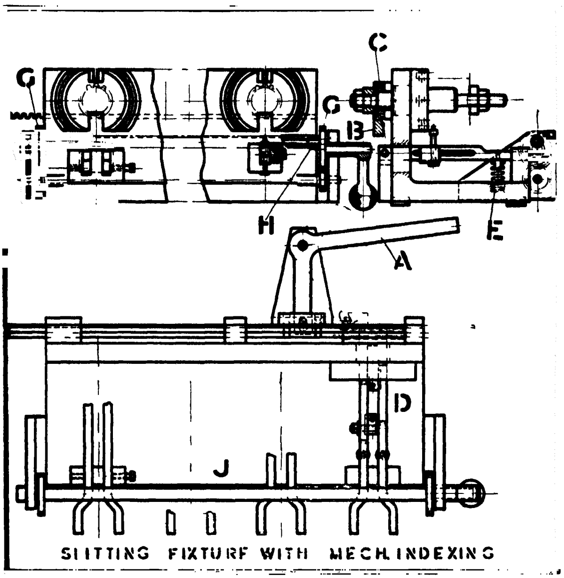


Fig. 19.—MULTIPLE SLITTING FIXTURE WITH MECHANICAL INDEXING

are each used for one operation, or set of slots, and are prevented from entering the wrong slots in the index plate by two masks, one of which is screwed to the top of the index plate and one to the underside. Whilst one plunger is in use the other is held out of engagement by the cam lever which operates it.

The index plate has been arranged in such a position that particles of swarf or dirt cannot interfere with its accurate functioning.

The tommy-holes *K* of which there are six, are included to enable a bar to be used for pulling the table round when indexing.

An interesting type of indexing fixture is shown in Fig. 18. The component to be milled is shown at *B* and a development of the same component is seen at *C*. The operation for which the fixture is designed is that of milling the two bayonet slots The component is mounted on the arbor *D* and is held in position by a nut and washer. The arbor is cut away, as shown in the section *AA*, to allow the cutter to project through the work. The arbor runs in two bearing bushes mounted in a sliding quill *E*, which is prevented from rotating by the key *F*. The sliding movement of the quill is controlled by the hand lever *G*, which operates through a pinion on to rack teeth cut on the quill.

Mounted on the arbor and keyed to it is a former *H*, in which are cut two slots of the same form as those required on the component. Engaging the slots in the former is a pin *J*, which is spring loaded to allow for indexing the arbor from one slot to the other. A hand wheel *K* is mounted on the end of the arbor. It will be seen that the movement of the arbor is controlled by the pin in the slot of the former *H*. The slot is cut in the component by an end mill of the correct width, and milling commences at the open end of the slot. By a combination of movement of the hand

lever and hand wheel, the operator is enabled to follow the pin along the former slot, and thus a corresponding form is produced on the component.

Splitting Bushes in Halves

The fixture shown in Fig. 19 is used for splitting bushes in halves. Four at once are located on this angle-plate fixture, which is bolted across the table of a horizontal milling machine. Four saws, correctly spaced, are mounted on the arbor, and after a cut has been taken through one side of the bushes they can be indexed to the opposite side and the operation completed.

The spigots holding the bushes can be indexed by altering the position of the lever *A*, which moves the rack *B* sufficiently to turn the gears *C* at the back of the spigot approximately 180°.

In order that the accuracy of the splitting is not affected by wear or backlash in the gears, it is arranged that the first slot is accurately located through the bars *D* beneath the spigots. The locating pin is held into the first saw cut by the springs *E*, and whilst milling the first saw cut, if there is no previously drilled hole in the bushes for location, the locating pin can be lowered by moving the knob handle *F*. This knob is connected to two pairs of gears, one pair at either end of the fixture at *G*.

Eccentric pins *H* are driven in the upper gears, and over these the rod *J* is fitted, which presses all four of the locating levers down at one time. This is also brought into operation whilst indexing.

The fixture was designed to be used for concentric bushes and also for bushes bored eccentrically ; hence the necessity for accurate location before and during splitting.

Chapter XIV

BROACHES

ALTHOUGH broaching is by no means a new process, it is only of recent years that its possibilities have been fully realised. This is largely due to the development of high-speed steel broaches, which give longer life and improved performance over those made of mild steel or carbon steel which were formerly used. These latter materials are still used on occasion, the mild-steel broach, in particular, providing a cheap tool for small quantities. Whereas for some years broaching was employed almost solely for producing internal forms, it is now being used increasingly on external work. The introduction of the hydraulic broaching machine has done much to further the use of broaching, and the mechanically operated machine has now been virtually superseded. The hydraulic machine is faster, smoother in operation, and allows high-speed steel broaches to be used to advantage.

Materials Suitable for Broaching

Broaching is successfully applied to both ferrous and non-ferrous material, but the best results on steel are obtained when the material is between the limits of 200 and 250 Brinell hardness numeral ; in consequence a heat-treatment operation is often required to bring the material to be broached into this condition. In common with other machining operations, apart from grinding, material that is too hard cannot be cut satisfactorily, and this factor must be studied carefully, particularly as the broach is one of the most expensive of cutting tools. Conversely, material that is too soft or " luggy " will tear, leaving a poor finish on the work, and often causing fracture of the broach teeth by crowding the gaps between the teeth.

Material for Broaches

The high-speed steel for broach manufacture should be carefully chosen, a typical analysis being :

Carbon	·65–·75 per cent.,
Tungsten	18 per cent. minimum,
Chromium	4 per cent.,
Vanadium	1 per cent. minimum,

but in order to obtain consistent results as regards both hardness values and cutting properties, the carbon content might well be controlled to within much closer limits, say ·69–·72 per cent. The blanks for use in

TABLE I.—PITCH OF BROACH TEETH

Pitch of teeth (inches) $= \cdot 35\sqrt{\text{length of hole (inches)}}$

Hole Length	*Pitch of Teeth*	*Hole Length*	*Pitch of Teeth*	*Hole Length*	*Pitch of Teeth*	*Hole Length*	*Pitch of Teeth*
1	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{5}{8}$	6	$\frac{7}{8}$	11	$1\frac{3}{16}$
$1\frac{1}{2}$	$\frac{7}{16}$	4	$\frac{11}{16}$	7	$\frac{15}{16}$	12	$1\frac{1}{4}$
2	$\frac{1}{2}$	$4\frac{1}{2}$	$\frac{3}{4}$	8	1	14	$1\frac{5}{16}$
$2\frac{1}{2}$	$\frac{9}{16}$	5	$\frac{13}{16}$	9	$1\frac{1}{16}$	16	$1\frac{7}{16}$
3	$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{7}{8}$	10	$1\frac{1}{8}$	18	$1\frac{1}{2}$

the manufacture of broaches should be hammered in two directions, that is, on the ends of the billet and then across its axis.

Broaches made from a case-hardening mild steel will function satisfactorily. Lighter cuts must be taken, however, on each tooth. A further disadvantage is that if there is more than one broach in the set, i.e. the depth of form is too great to be produced by one broach due to the excessive length that would be required, the broaches largest in diameter cannot be ground down when under size to the dimension of the smaller broaches, because the regrinding will remove the hard case. When one broach only is required and tool cost must be kept low, the mild-steel broach should be considered. No hardening equipment is required beyond that already installed in most engineering works, horizontal furnaces being satisfactory, and the broaches, having a soft core, can be readily straightened to correct any undue distortion before being finally ground to size.

The design of broaches, whether used in horizontal, vertical, pull- or push-type machines, is governed by the same general principles, which are as follows.

Pitch of Teeth

The pitch of the teeth depends primarily on the length of the part being broached, but also on the material to be cut. Suitable pitches for various work lengths are given in Table I. A general rule for spacing broach teeth is given by pitch of teeth (inches) $= \cdot 35\sqrt{\text{length of hole (inches)}}$.

The pitch should be such that at least two to three teeth are cutting at any time; in other words, the third tooth should have commenced cutting before the first has finished.

In order to produce a smoother finish and prevent a tendency to chatter, the pitch may be varied or staggered slightly from one tooth to another. No definite rule is necessary for the amount of variation, but from $\frac{1}{64}$ in. to $\frac{1}{32}$ in. for small broaches up to $1\frac{1}{2}$-in. diameter and up to $\frac{1}{16}$ in. for larger broaches proving satisfactory.

In order to avoid "hammering" on rectangular broaches, the cutting edges may be inclined to the axis, the teeth on opposite sides being inclined in opposite directions in order to balance the sideways forces thus introduced. The foregoing rules for determining the pitch of teeth must be modified to suit certain conditions, some of which are as follows :

(*a*) On long components the pitch may be shortened and the chip space made correspondingly deeper, where the diameter of the broach is big enough to allow of it. This will serve also, when desirable, to reduce the overall length of the broach.

(*b*) On components where the length to be broached is short, the pitch of the teeth must be such that there is always at least one tooth in contact with the work. This is necessary to prevent "hammering" in the broaching machine and to prevent the work moving sideways on the broach. It will be realised that the variation in the load placed on the machine when there are two and three teeth, as a minimum, cutting alternatively as the broach passes through the work, is less than would be the case if one and two teeth were in operation, and is to be preferred, although not always possible.

When broaches for "thin" pieces are designed for horizontal machines, the pitch of the teeth must also be such that one tooth at least is always cutting, so preventing the work from falling between the broach teeth. In order to obtain a better design of broach on such pieces it is usual, if quantities are sufficient and the end faces are flat, to clamp a number together in a fixture. When this is possible the broach can be designed to suit the quantity selected, and normal practice adopted.

(*c*) The pitch of the teeth should be such that there is ample room for the chip, and until experience is gained this should be calculated. The volume of space should exceed that of the chip by at least an equal amount. If, however, this is not practicable, one-third greater space than the chip will occupy should be the minimum.

(*d*) The number of teeth cutting at one time depends on the depth of cut and material to be broached and is governed by the maximum pull of the machine being used. On long components, therefore, it may be found necessary to extend the pitch in order to reduce the load required to pull the broach. The formula given later should be applied in such cases in particular.

Load on Broach

After deciding preliminary dimensions for tooth spacing from the foregoing considerations, the next step is to calculate the effort required to pull the broach through the work. Adjustments can be made, if necessary, as described in item (*d*) above.

The pitch is selected from Table I, always choosing the next highest figure when the work length falls between the tabulated figures. The pull may then be calculated as follows :

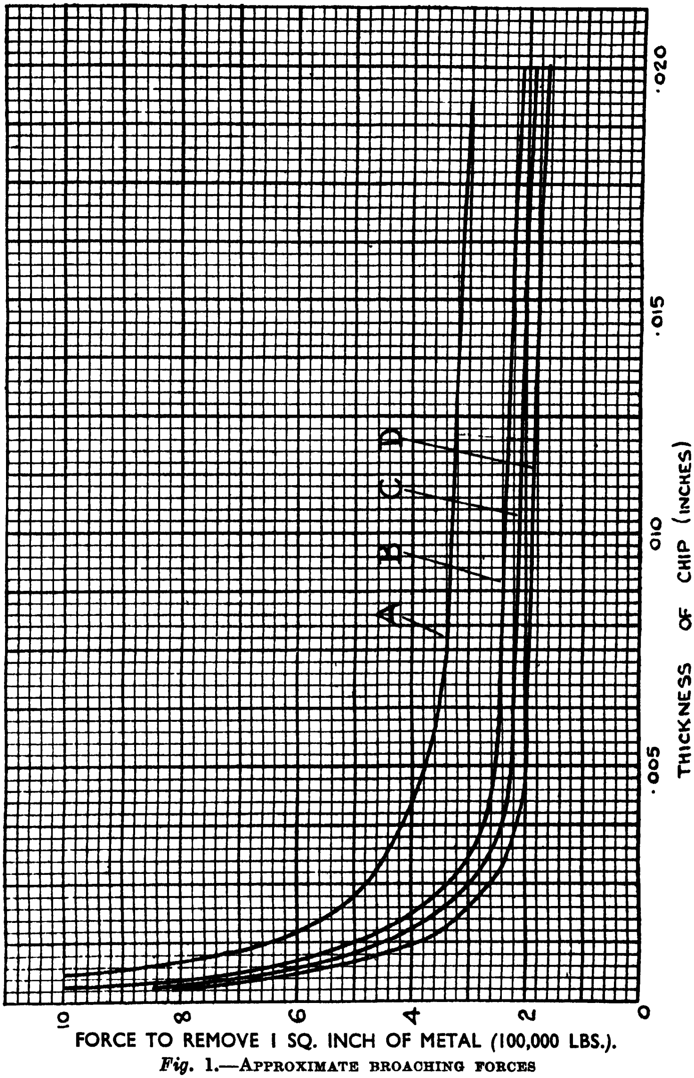


Fig. 1.—Approximate broaching forces

Curves give force required to remove 1 sq. in. of metal. Load on broach = area of chips being removed multiplied by load to remove 1 sq. in. = circumference of cut multiplied by thickness of chip multiplied by number of teeth cutting multiplied by load to remove 1 sq. in. For ordinary alloy steels use A curve; for machine steels and low carbon steels use B curve; for soft cast iron use C curve; for malleable iron use D curve.

TABLE II.—AVERAGE CUT PER TOOTH

Type of Broach	*Chip Thickness* *In.*
Round holes	·002
Splines	·0025
Rectangular	·003
Keyways	·0035

The above figures are suitable for general use on steel, cast iron, and aluminium. When broaching bronze, the cut per tooth may be up to ·020 in., due to its free cutting qualities. The above figures may be increased or decreased up to 40 per cent. to suit varying conditions.

The pull or load on a circular broach—i.e. for broaching a round hole = area of metal removed by teeth in contact with work multiplied by the load required to remove 1 sq. in. of metal = circumference of hole multiplied by the number of teeth in contact lengthwise multiplied by the thickness of chip (arbitrarily chosen) multiplied by the table value (Fig. 1). For splined holes, instead of using the circumference of the hole in the above formula, the length of cutting edge of one ring of teeth should be used, generally represented by the width of spline multiplied by the number of splines. On flat surfaces or irregular forms the length of cutting profile should be computed.

The load required to remove 1 sq. in. of metal can be found from the graph Fig. 1, which has been constructed from the experience obtained on many components in practice as recorded on a hydraulic broaching machine. The figures given in the graph are for materials of normal machineability and are approximate only. The designer should allow a margin on the figures obtained to allow for contingencies, and if the broaching machine has a valve for restricting the pull, this should be set slightly higher than the calculated figure. Average cuts per tooth are given in Table II.

Having obtained the required load, steps should be taken to verify that it is not above the capacity of the machine for which the broaches are intended ; and whilst the maximum thickness of chip should always be chosen, where it is intended that two or more broaches are to be pulled at one cycle, then the chip thickness must be adjusted to keep the total load within the pulling capacity of the machine. The smallest section through the broach and the strength of the pulling end should be checked to ensure that these portions will more than carry the load to which the broach will be subjected. A factor of safety less than four to one should not be tolerated. Wherever possible, this factor should be as high as possible in case shock through unexpected accident should occur.

Broaches are running with a fair measure of success with a factor of safety of only three to one, the peculiarities of the design not permitting an alternative. For normal work, however, this would be bad practice.

TABLE III.—CUTTING ANGLES FOR BROACH TEETH

Material	*Front Cutting Angle*
Steel Tubes	12–15°
Copper	15°
Aluminium	10–12°
Steel Forgings	7–10°
Cast Steel	7–10°
Cast and Malleable Iron	0–5°
Bronze	0°

Chip Clearance

The shape of the chip clearance is important, and the values of the front rake or undercut given in Table III will serve as a guide for most classes of work. The aim of the designer should be to obtain a chip which rolls easily and can be brushed from the teeth, whereas broken and crushed chips will remain on the broach and may eventually cause fracture of the teeth. To enable the chip to roll, it may be necessary to experiment with different cutting angles on samples of the material. The radius at the root of the tooth is very important and should be as generous as possible to assist in rolling the chip and to add strength to the tooth.

Tooth Shape

The broach tooth should be as strong as possible whilst allowing for a reasonable chip space. A " land " of approximately ·010 in. in width should be left on the tops of sizing teeth ; that is, they are not backed off to a sharp edge, but are full circular diameter for this length. The cutting teeth, however, should be ground to a sharp cutting edge and then backed off approximately ·003 in. on the diameter in a length of ·10 in. (see Fig. 2). In this manner, although no " land " is left, the broach does not lose its size too quickly on being sharpened, which is done on the front of the teeth, the final sizing teeth providing adequate reserve.

Whenever the width of cut is considerable, such as is found in circular and slab broaches, the teeth should be nicked to break up the chips ; these nicks should be staggered to allow the following tooth to remove the metal left by the nick on the preceding tooth.

The foregoing considerations having resulted in the determination of tooth pitch and depth of cut, and the load having been checked against the strength of the broach and the maximum pull of the machine, it may be necessary to adjust the figures obtained as follows :

(*a*) Tooth pitch may be increased to reduce the total load on the broach or decreased to take advantage of the pull available on the machine.

(*b*) The thickness of the chip may be reduced to decrease chip volume, or increased to take advantage of a chip space which would be less than half filled.

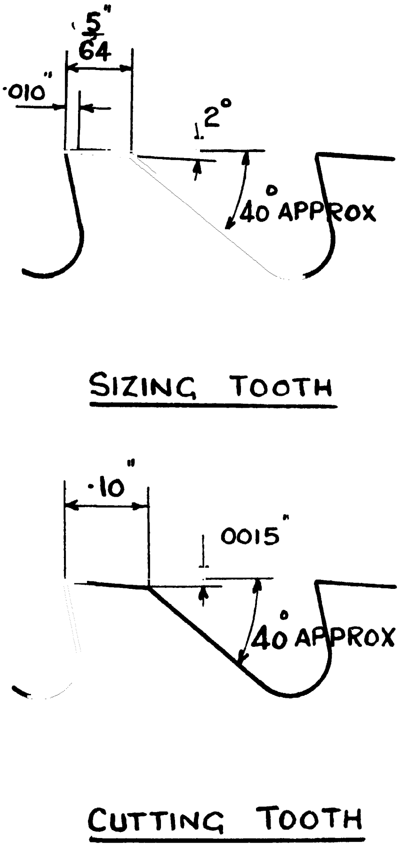


Fig. 2.—EXAMPLES OF BROACH TOOTH FORM

If any of the above factors are varied, care should be taken to make a further check on the others; for instance, an increase of chip thickness or decrease in pitch would necessitate a further check on the total pull required on the broach. It should be noted from Fig. 1 that the load to remove 1 sq. in. of metal does not vary in direct proportion to the chip thickness.

Allowance for Broaching

Having determined tooth pitch, chip thickness, and load, it is necessary to decide the amount of metal to be removed by the broach before being able to calculate the number of teeth and length of broach.

Because broaching is an economical method of obtaining high finish and close accuracy, sufficient material must be allowed in order that the broaching operation will remove any irregularities in the original hole, whether due to tool marks, torn finishes, or similar unavoidable eventualities. A broaching allowance of ·040 in. is sufficient when the broaching is done from a previously drilled hole and if, for some production reason, it has been found necessary to produce the original hole by a finer method of machining than drilling, such as reaming, ·020 in. on diameter would be found to be adequate.

The first cutting tooth on the broach should be made minus ·002 in. below the small limit of the original hole. This is necessary in case the hole should have been produced slightly smaller than standard and is done to prevent the first tooth being overloaded. The finished size of the cutting teeth when broaching steel should be made larger than the finished size required by a like amount, i.e. ·002 in. This is sometimes necessary because of the tendency for splined parts to close in slightly

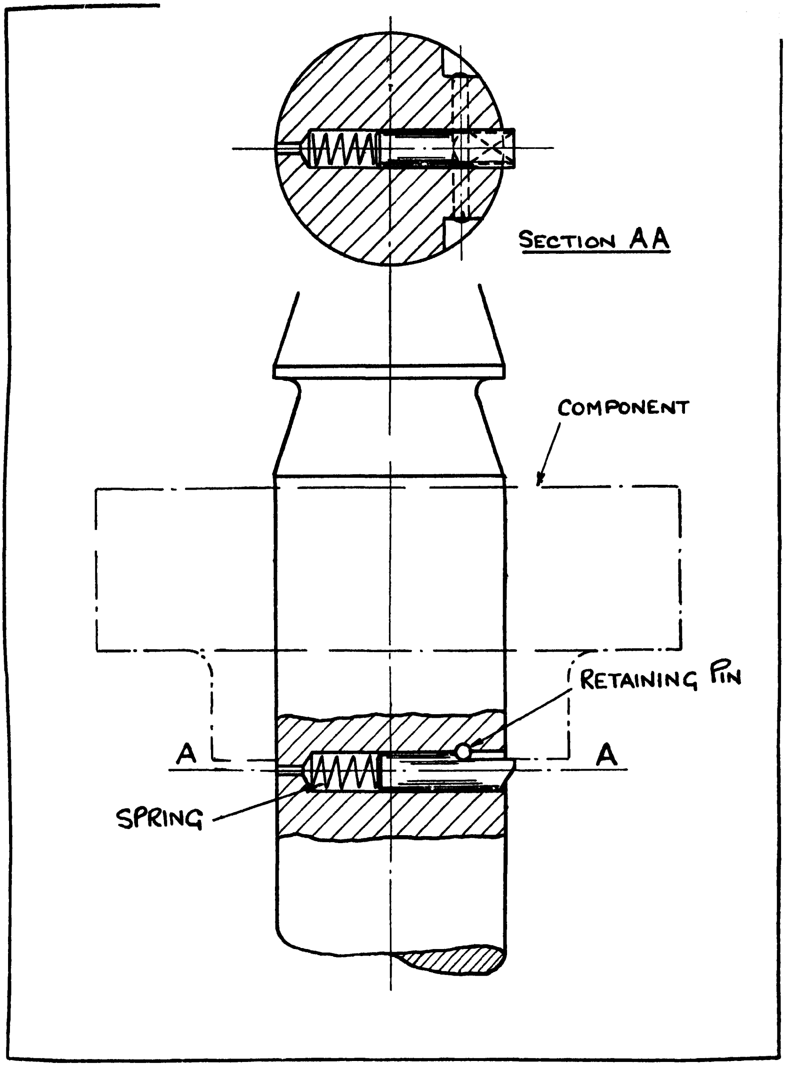


Fig. 3.—EXAMPLE OF CATCH FOR RETAINING COMPONENT ON BROACH ON VERTICAL MACHINE

after the broach has passed through. Whilst such an allowance for shrinkage is unnecessary when broaching cast iron and non-ferrous metal, it is, in any case, a very wise precaution to take because it is so easy to make adjustments on the broach by grinding, in the event of it cutting over size on the first component.

The calculation for circular or spline broach is as follows :

N = number of teeth cutting

$$\text{for steel } N = \frac{\begin{matrix}\text{(finished hole size)} \\ \text{(+ ·002 in. shrinkage)}\end{matrix} - \begin{matrix}\text{(rough hole size)} \\ \text{(− ·002 in. for lead in)}\end{matrix}}{2 \times \text{thickness of chip}} + 6 \text{ additional teeth for sizing}$$

$$\text{Keyway broach } N = \frac{\text{depth of keyway}}{\text{thickness of chip}} + 6 \text{ additional teeth for sizing}$$

Total length of broach = L + length of work + thickness of fixture and face plate or table + length of adapter at pulling end + length of end for broach lifter when used (L = length of cutting portion of broach).

On the type of vertical broaching machine where the work is placed over the shank at the lower end of the broach, a catch is necessary to prevent the work falling. An example of such a catch is as Fig. 3, and a slight increase in broach length is required, sufficient to cover the length occupied by the catch.

Types of Broaches

Among the following examples are shown types of broaches in general use together with some specialities. It is not possible in this section to show representative examples of each type of broach, but the foregoing principles can be applied in all cases. Broaches are included for :

(1) Keyways.
(2) Round holes.
(3) Splined holes.
(4) Surface broaching, and also descriptions of:
(5) Built-up broaches.
(6) Broaches with inserted teeth.

Keyway Broach

Fig. 4 shows a standard type of keyway broach. These are used in conjunction with the bushes shown in the section following on "Broaching Fixtures." The broach shown is for cutting a standard $\frac{5}{16}$-in. wide keyway.

It will produce this keyway in any size of hole, it being necessary to supply a guide bush for each size, to bring the broach into its correct relative position in the hole. It will be noticed that the thread *A* for attaching the broach puller, by which the broach is coupled to the slide of the machine, is offset. This is done to bring the pull in line, as nearly as possible, with the cutting teeth, so avoiding the introduction of bending stresses in the broach.

The width *B* on the broach is made a sliding fit in the slot in the guide bush.

Broach for Round Hole

Fig. 5 shows an example of broaching in its simplest form—that of sizing a round hole in a component which has been previously rough-drilled and faced. In this instance no fixture is required, the thrust of the cut being taken on a bush in the face plate or table of the machine, the diameter of the hole in the bush being approximately $\frac{1}{16}$ in. larger than the largest diameter of the broach. The design of such a broach is undertaken as follows :

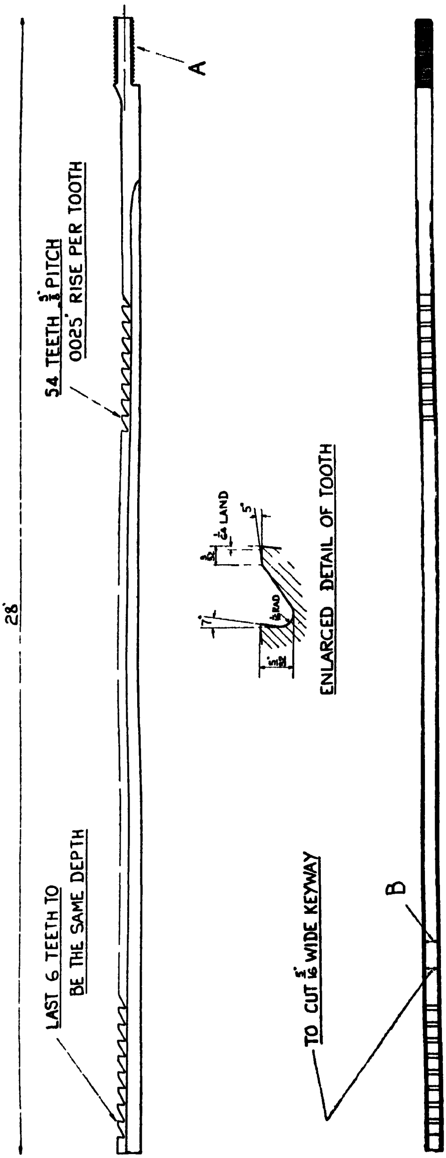


Fig. 4.—KEYWAY BROACH

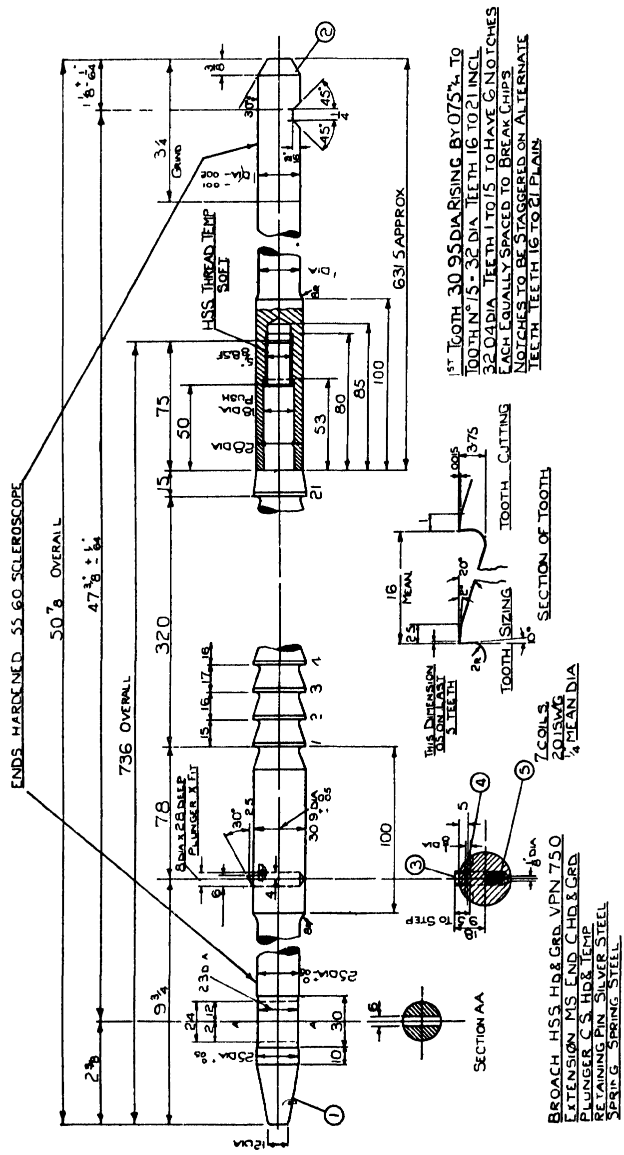


Fig. 5.—CIRCULAR BROACH

Data supplied:

(1) Material to be broached — steel forging.
(2) Length of broached hole — 75 mm.
(3) Dia. of rough-bored hole — 31 mm.
(4) Dia. of finished hole — 32 mm. $\begin{smallmatrix} + \cdot 00 \text{ mm} \\ - \cdot 025 \text{ mm.} \end{smallmatrix}$
(5) Maximum stroke of machine — 58 in.

Then, 75 mm. = approximately 3 in., and from Table I pitch of teeth = $\frac{5}{8}$ in., say 16 mm.
or applying the formula:

$$\begin{aligned} \text{pitch} &= \cdot 35 \sqrt{\text{length of hole}} \\ &= \cdot 35 \sqrt{3 \text{ in.}} \\ &= \cdot 35 \times 1\cdot 732 = \cdot 606 \text{ in.} \end{aligned}$$

say $\frac{5}{8}$ in or 16 mm.

∴ If a pitch of 16 mm. is used, there will be a maximum of 5 teeth and a minimum of 4 teeth cutting at any one time.

Assume cut per tooth = ·075 mm. or ·003 in. on diameter, then chip thickness will be ·0015 in. and, to find total pull on broach, area of metal being removed

$$= 1\cdot 26 \text{ in.} \times \pi \times \cdot 0015 \text{ in.} \times 5$$
$$(1\cdot 26 \text{ in.} = 32 \text{ mm.})$$
$$= \cdot 0297 \text{ sq. in.}$$

Then from Fig. 1 force to remove 1 sq. in. of metal with a chip thickness of ·0015 in. is approximately 600,000 lb. (*A* curve),

and load on broach

$$= 600{,}000 \times \cdot 0297$$
$$= 17{,}820 \text{ lb.}$$

To check stress on broach, root diameter = 31 — 2 (3·75 depth of tooth) = 23·5 mm.

∴ Stress on this section

$$= \frac{\text{Total load}}{\text{Area of section}} = \frac{17{,}820 \times 4}{\pi \times \left(\frac{23\cdot 5}{25\cdot 4}\right)^2} = \frac{26{,}520 \text{ lb. sq. in.}}{(25\cdot 4 \text{ mm.} = 1 \text{ in.})}$$
$$= 11\cdot 8 \text{ tons/sq. in.}$$

No reliable figures can be given for the tensile strength of high-speed steel in its hardened condition. The material is very brittle and has a small percentage of elongation. It is more important to guard against shock than extremes of tensile load. A figure of 80 tons per square inch may be used for the purpose of checking tensile strength, and the figure of 11·8 tons per square inch obtained above should therefore be quite safe. No trouble has been experienced with this broach in practice. To check chip space:

Area of section of chip space

$$\frac{(16 - 2{\cdot}5)\,3{\cdot}75}{2} \text{ approximately}$$

$$= 35 \text{ sq. mm.}$$

Area of sections of chip

$$= {\cdot}0375 \text{ mm.} \times 75 \text{ mm.} = 2{\cdot}8 \text{ sq. mm.}$$

To find number of teeth :

Smallest dia. = 30·95 dia. (·05 mm. below dia. of bored hole)
Largest dia. = 32·04 dia. (allowing ·05 mm. for closing in)

∴ No. of cutting teeth (·075 rise on dia.)

$$= \frac{32{\cdot}04 - 30{\cdot}95}{{\cdot}075}$$

= 14 teeth with ·075 mm. rise and 1 tooth with ·040 mm.

∴ We have

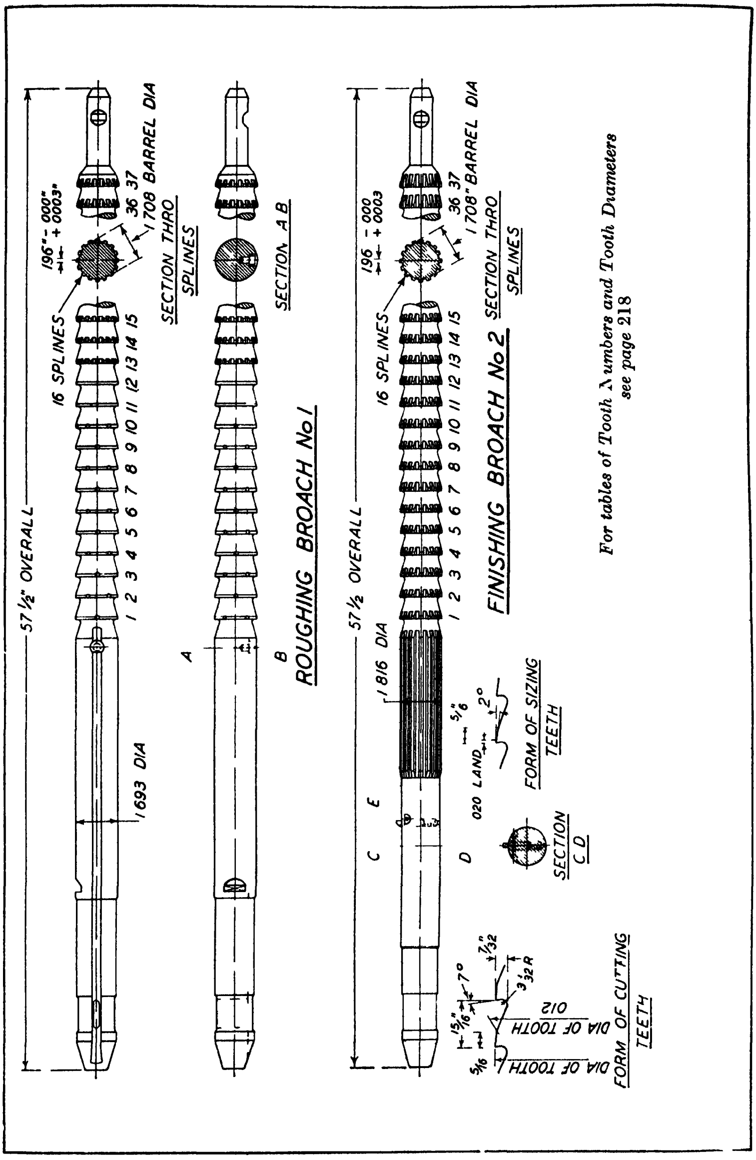
dia. of pilot 30·90 mm.
,, No. 1 tooth 30·95 mm.
rising by ·075 mm. per tooth to
No. 15 tooth 32·00 mm. dia.
dia. of No. 16 tooth 32·04 mm. dia.

and teeth Nos. 17 to 21 are sizing teeth of the same dia.

The pitch of the teeth is staggered 1 mm. each way from the calculated pitch. It will be noticed that the rear section of the broach is made of mild steel and is case hardened and ground. This is done to economise in high-speed steel, since this section has only to support the weight of the broach whilst loading the component into position, and no actual broaching load is transmitted through it. The cotter slot on the front end and the supporting groove on the back end of this broach are to suit the particular machine for which it is designed.

Broaches for Splined Hole

In Fig. 6 is illustrated a pair of broaches for producing a splined hole in a coupling. The broaches are used on a vertical machine, and the roughing broach operates in conjunction with the fixture shown in the section on " Broaching Fixtures." The finishing broach is used without a fixture. Teeth numbers 1 to 12 on the roughing broach are for truing up the bored hole in the component, and it will be noticed that the first ten of these teeth are nicked in order to break up the chips, leaving teeth numbers 11 and 12 to clean up the bore before commencing to broach the splines. The pilot of the finish broach is splined and is made an easy push fit in the hole produced by the roughing broach. The component is held in position on the pilot, until cutting commences, by the spring plunger *E*. It will be seen that the broaches cut on the outer diameters only, and that each splined tooth is producing the finished



For tables of Tooth Numbers and Tooth Diameters
see page 218

Fig 6 —Splined Broaches

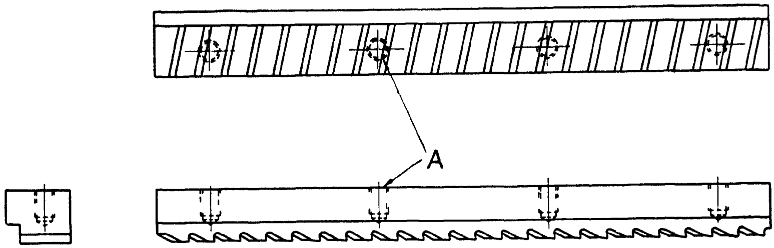


Fig. 7.—Surface broach insert

width of splines. The two broaches are used side by side in the machine, and a finished component is produced during each cycle of the machine.

Surface Broaches

The development of surface broaching has lagged behind internal broaching, due to the fact that efficient milling machines, suitable for external machining operations, have been available for many years, whereas, prior to the development of internal broaching, the only reasonable way of producing irregular internal shapes was by slotting—never a very efficient or fast process. Surface broaching is now being rapidly developed as a fast production operation, and the modern hydraulic machines are doing much to further this development.

The design of broaches for external work follows the same principles as previously outlined for producing holes. The usual practice is to make the broaches in sections, about 9–12 in. in length, and to mount the sections in a broach slide or holder. Each section is easily removed for regrinding or replacement should a tooth become broken. The broaches are used in one of two ways—either the broach is stationary and the work is passed over it, or the broach inserts are mounted in a slide which is

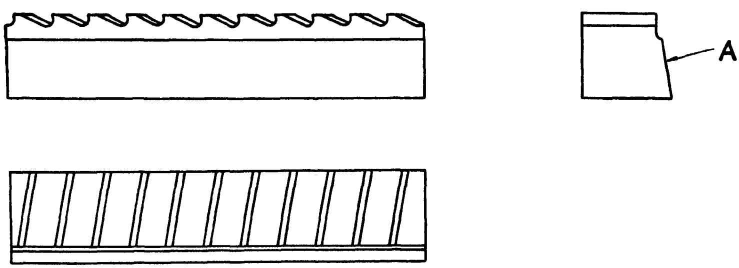


Fig. 8.—Surface broach insert

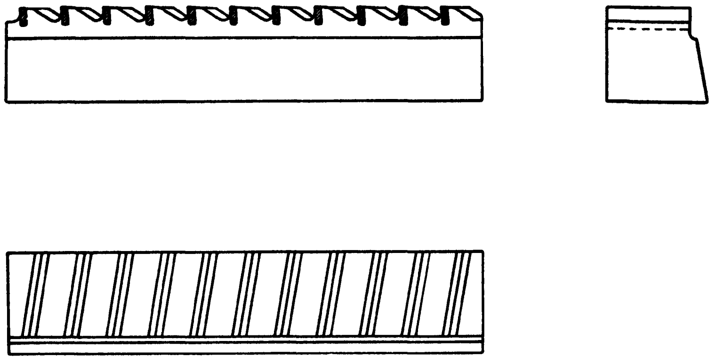


Fig. 9.—Surface broach insert with cemented carbide teeth

traversed along the work. On broaches for flat surfaces, the teeth should be at an angle to the axis of the broach in order to prevent "hammering" and to provide a more uniform load on the machine.

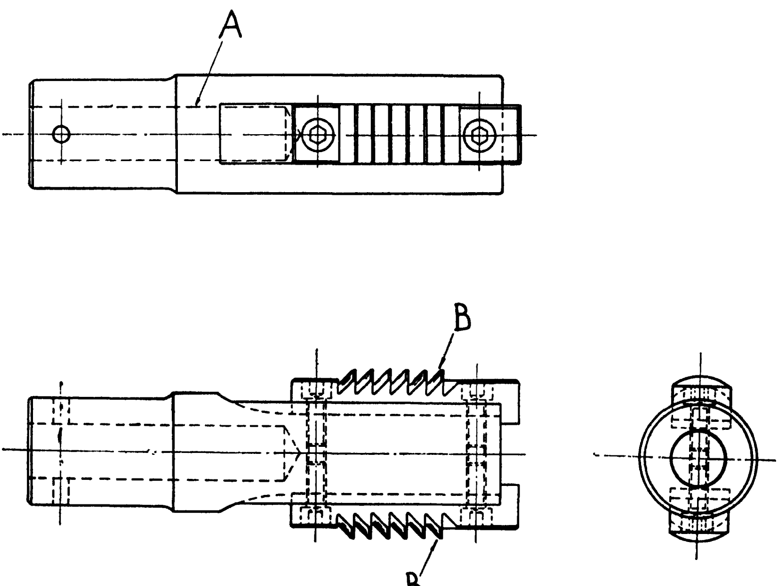


Fig. 10.—Built-up push broach

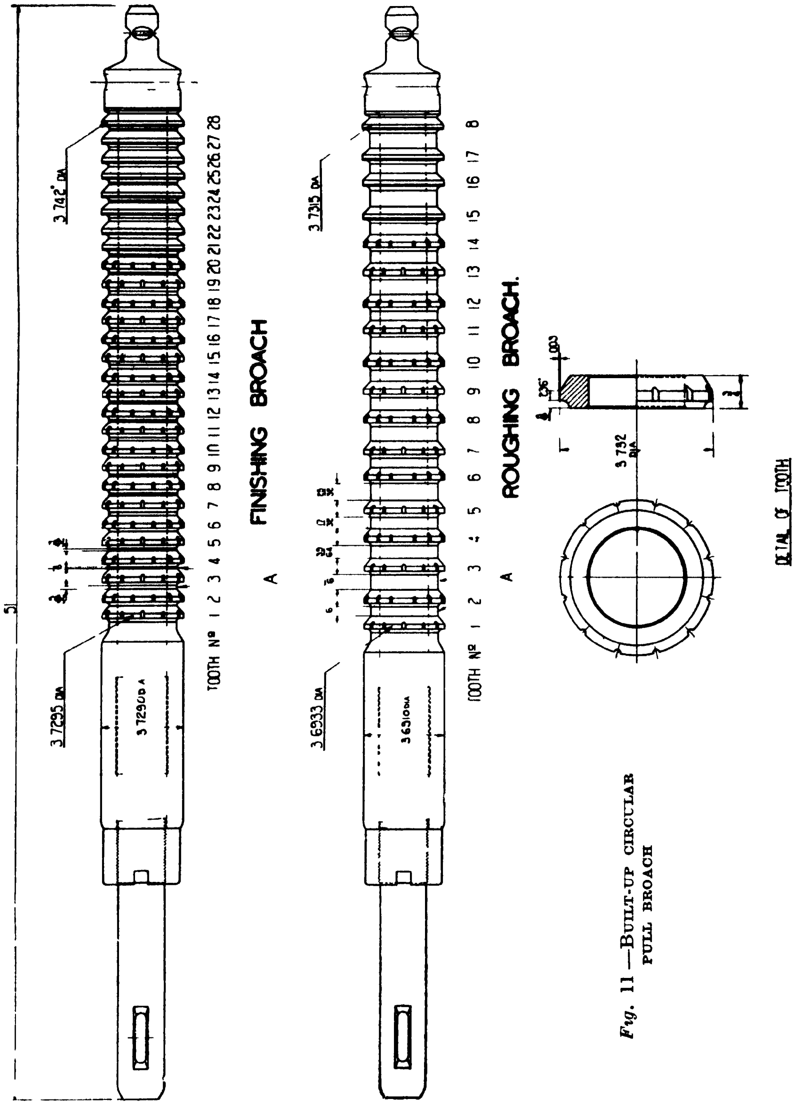


Fig. 11.—BUILT-UP CIRCULAR PULL BROACH

In Figs. 7 and 8 are seen typical examples of broach inserts for external work. That shown in Fig. 7 is held into the broach slide by screws in the tapped holes *A* in the rear face, and the example in Fig. 8 is held back by a taper wedge against the face *A*.

Such broaches lend themselves very well to being tipped with cemented carbide on the teeth, and good results have been obtained in practice. They are expensive to produce, but have given up to five times the life of similar broaches of high-speed steel. It is sometimes the practice to use high-speed steel for roughing teeth and teeth tipped with cemented carbide for finishing, in order to maintain size and form for a longer period. Fig. 9 shows a broach insert tipped with cemented carbide.

Built-up Broaches

On medium or large broaches considerable economies may often be effected by having the teeth only of cutting material and the remaining portions of the broach of a cheaper grade of steel. Fig. 10 shows a simple example of this and consists of a mild-steel holder *A*, case hardened and ground, which carries two small broach inserts *B* in slots, one on each side. The inserts are thus easily replaceable and are quite cheap to manufacture. The example shown is used for broaching clearance slots in bearings.

Teeth

Fig. 11 shows another example of built-up broaches and consists of a rougher and finisher for a large hole approximately 95 mm. dia. The teeth on these broaches are made in the form of a series of rings of a standard size for both broaches, as shown in the detail sketch. The teeth are all made initially to the size of the largest ones—the sizing teeth on the finishing broach—and are ground to their appropriate size when assembled in the broaches.

When Broaches become Undersized

Thus, when the broaches become undersized, it is only necessary to scrap several of the smaller teeth—those on the front of the roughing broach—and replace some of the larger teeth, the intermediate ones being moved along the broaches to suit. If a tooth breaks in service, it is a simple matter to replace it from stock and grind the new tooth to size when assembled in position.

It will be seen that the cutting teeth on both broaches are nicked, the sizing teeth being left plain, and once a tooth is nicked it can only be used in another nicked position, plain teeth being reserved for sizing. The notches are staggered when assembling the teeth, but their actual radial positions are not important. The pitch of the teeth is staggered by providing a series of mild steel, case-hardened washers *A* of varying thicknesses, which are assembled between the teeth as shown.

The cut per tooth on the roughing broach is approximately ·070 mm. on the diameter, and the cut per tooth on the finisher is between ·011 mm. and ·018 mm., the pitch being made correspondingly small, the fine cut providing a good finish in the bore of the component. The arbors used on these broaches are made of nickel-chrome steel, toughened. The broaches shown in this example were designed for use on malleable iron castings.

TOOTH NUMBERS AND TOOTH DIAMETERS FOR SPLINED BROACHES
(*see* Fig. 6)

No. 1 Broach

Tooth No.	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*
	In.		*In.*		*In.*		*In.*
1	1·695	10	1·712	19	1·745	28	1·790
2	1·697	11	1·712	20	1·750	29	1·795
3	1·699	12	1·712	21	1·755	30	1·800
4	1·701	13	1·715	22	1·760	31	1·805
5	1·703	14	1·720	23	1·765	32	1·810
6	1·705	15	1·725	24	1·770	33	1·815
7	1·707	16	1·730	25	1·775	34	1·820
8	1·709	17	1·735	26	1·780	35	1·820
9	1·711	18	1·740	27	1·785	36	1·820
						37	1·820

No. 2 Broach

Tooth No.	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*	*Tooth No.*	*Tooth Dia.*
	In.		*In.*		*In.*		*In.*
1	1·820	10	1·865	19	1·910	28	1·955
2	1·825	11	1·870	20	1·915	29	1·960
3	1·830	12	1·875	21	1·920	30	1·965
4	1·835	13	1·880	22	1·925	31	1·970
5	1·840	14	1·885	23	1·930	32	1·971
6	1·845	15	1·890	24	1·935	33	1·971
7	1·850	16	1·895	25	1·940	34	1·971
8	1·855	17	1·900	26	1·945	35	1·971
9	1·860	18	1·905	27	1·950	36	1·971
						37	1·971

Chapter XV

BROACHING FIXTURES

MOST internal broaching work can be done without the use of special fixtures, the provision of hardened bushes which fit the hole in the machine table only being necessary. Such bushes are made large enough in the bore to clear the largest diameter of the broach by approximately $\frac{1}{16}$ in. all round the periphery. They are used whenever the component presents a flat face at right angles to the axis of the broach and which can be located against the bush to take the thrust of the cut. On vertical machines, however, it is preferable to slide the work over the leading end of the broach, where it is held in position by a spring plunger similar to that shown in Fig. 3, page 207, and retained until brought down on to the bushing by the downward movement of the broach.

Keyway Broaching

Other simple broaching fixtures are the various spigots used when broaching keyways. Fig. 1 shows an example of such a spigot. Diameter *A* is made to fit the hole in the machine table, and the flat *B* is located against a shoulder or plate on the table to prevent movement of the spigot. Diameter *C* is made a push fit in the component, whilst the bottom of the groove *D* controls the depth of keyway to be cut—the total depth of the groove plus the depth of keyway required equalling the maximum depth of the broach at the largest end. By using a hardened shim similar to that shown at *E*, it is possible to cut a keyway deeper than the total cutting depth of the broach. The broach is pulled through the work in the usual manner, and then the shim is placed in the bottom of groove *D* and the broach is pulled through again. The lip shown on the shim bears against the end of the spigot and prevents the shim being pulled through the slot by the friction of the broach. When using such shims, care must be taken to ascertain that when making the second pull the first tooth on the broach is not overloaded.

When a keyway is required in a taper hole with the bottom of the keyway parallel to the axis, then the spigot would be made as shown in Fig. 2, the spigot being made tapered, the diameter of which should be to suit the bottom limit of the hole in the component. The nut *A* on the threaded part of the spigot can be turned against the workpiece and so take the thrust of the cut, at the same time preventing the component from locking on the taper spigot. The nut is necessary, because the toler-

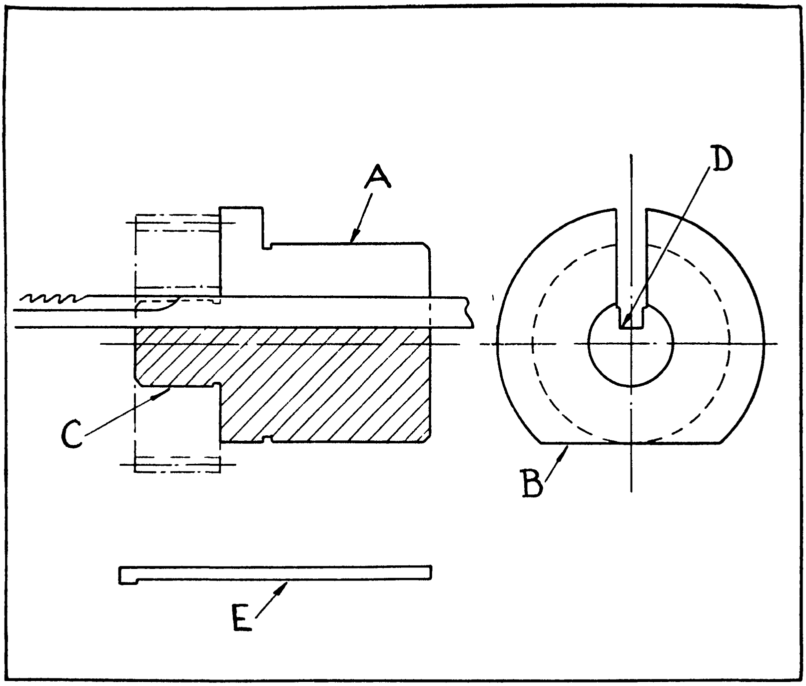


Fig. 1.—SPIGOT FOR KEYWAY BROACHING

ance on the hole permits a variation in the position that the component will assume along the spigot. The nut can also be used for removing the work.

When the bottom of the keyway in a taper hole is required parallel to the taper, the fixture used is similar to that shown in Fig. 3, with the work locating spigot arranged with its axis at an angle to the centre line of the fixture and broach guide, so presenting the work in the required position. In this example the keyway is required to be located radially in relation to the holes in the flange, and a locating peg is provided for this purpose, the fixture being flanged and increased in diameter to accommodate this added location.

Broaching Splines

Another of the problems to be met with is the necessity for broaching splined holes with the spline in definite relationship with another hole or lug in the component, and the fixture shown in Fig. 4 shows the fundamental requirements of fixtures of this type.

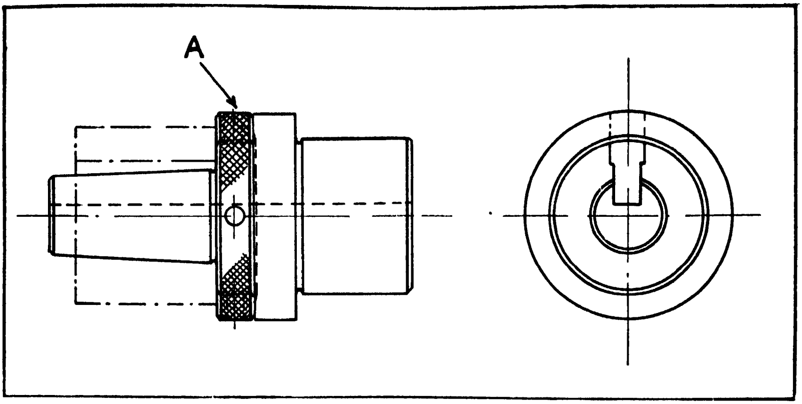


Fig. 2.—SPIGOT FOR BROACHING KEYWAY IN A TAPER HOLE

It will be seen that the broach has a fixed radial location with the fixture, because a key in the pilot bush engages with a keyway on the shank of the broach. The pilot bush is positioned in the fixture or adaptor plate in a like manner, thus preventing any radial movement between broach, pilot bush, and fixture which carries suitable locating pins to position the lug on the component.

In operation, the pilot is withdrawn from the fixture by encountering a shoulder on the broach, the length of the bush being arranged so that all the keys are in engagement until sufficient teeth are cutting to stop radial movement of the component.

Fixture for Vertical Machine

A broaching fixture of similar purpose to that already described, but of different design, is shown in Fig. 5 and is for use on a vertical machine. In this case the fixture consists of a block *A*, to which are fitted two side plates *B*, which carry two sliding vees *C* for locating the arms of the component. The two plates *C* are spring loaded to allow for variations in the length of the component and also to ensure that both arms of the component are located. Bush *D* is a push fit in the bore of block *A* and is prevented from rotating therein by a key *E*. The bore of the bush *D* is made a push fit for the broach pilot. Another key *F* is fitted to the bore of the bush and slides in a keyway on the broach. Thus it will be seen that the broach is located in correct radial position with the locating vees *C* and is held in this position until the broach has cut its own location in the bore of the component.

In its loading position, the table of the machine is in a position sufficiently far below the lower end of the broach, which is suspended by its

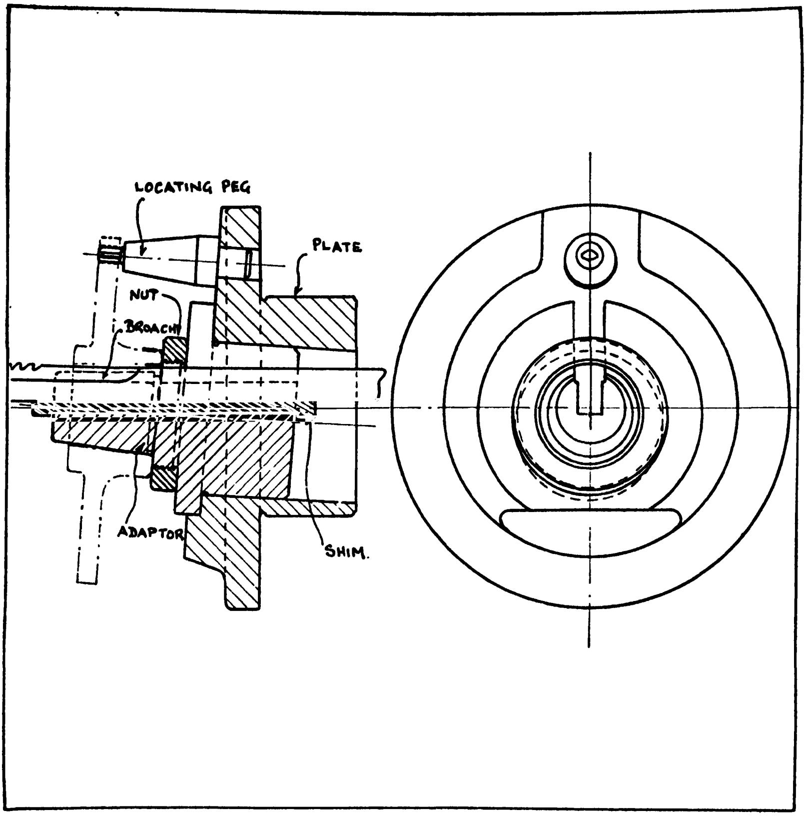


Fig. 3.—Broaching a taper keyway with a radial location

upper end, to allow the fixture with the component in position to be raised over the broach shank, where it is prevented from falling by the trigger *G*, which engages a notch cut in the broach shank. As the automatic cycle of the machine commences, the broach first descends until the lower end enters the broach puller on the machine, after which a cotter feeds through the slot in the broach shank. Then the table commences to rise and lifts the fixture with it, trigger *G* releasing itself.

When key *F* strikes pin *J* in the broach shank, bush *D* is prevented from further movement and is released by the spring plunger *H* and allowed to fall until the trigger *G* engages the notch on the broach. Bush *D* remains in this position until the completion of the cycle, when it is removed to enable a new component to be loaded. By the time the bush

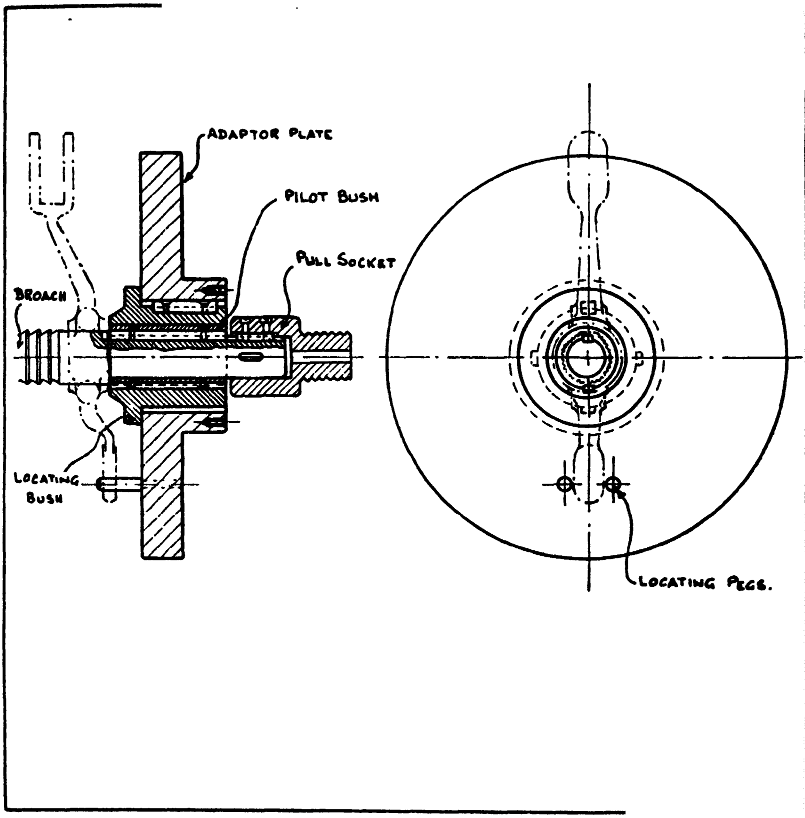


Fig. 4.—FIXTURE FOR MAINTAINING ALIGNMENT OF SPLINES AND ARMS OF COMPONENTS

is released, as described above, the broach has entered sufficiently far into the component to provide adequate location and prevent radial movement. Two broaches are used for this component and the fixture described above is used with the roughing broach. No fixture is required for finishing, the component being located on the broach shank by the splines previously partly broached. The two broaches are used side by side on one machine and were shown in Fig. 6, page 213.

Multi-spline Indexing Fixture

Where the economics are such that a multi-splined broach would be ruled out, because of initial cost, use can be made of a single keyway broach combined with an indexing fixture to give the required division.

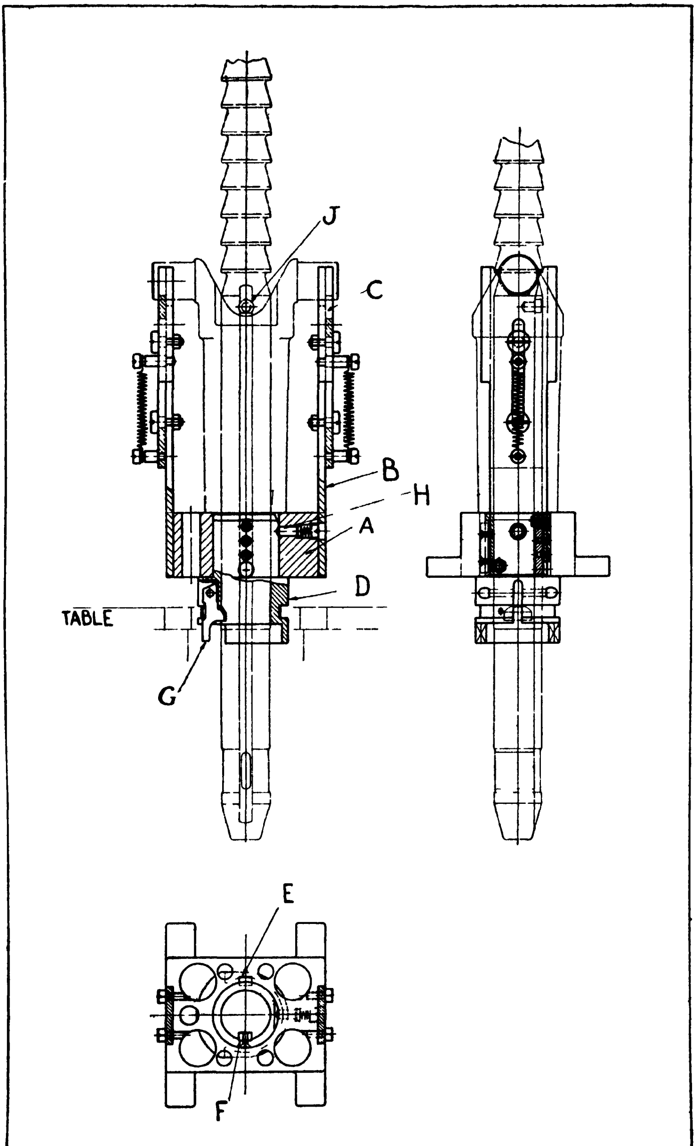


Fig. 5.—FIXTURE FOR VERTICAL MACHINE

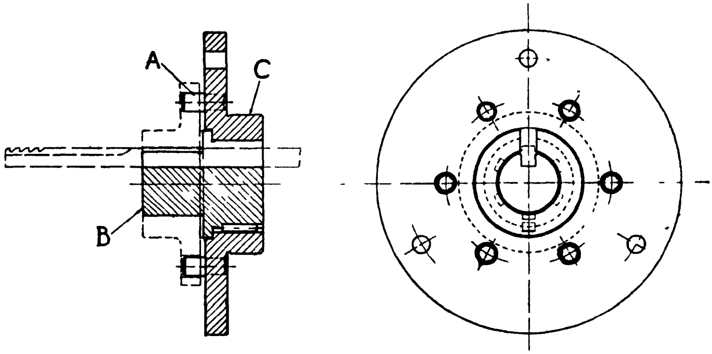


Fig. 6.—MULTI-SPLINE INDEXING FIXTURE

Such a fixture is shown in Fig. 6, use being made of six holes in the flange of the component. Five of these holes are drilled to the size specified, but the sixth is drilled and reamed $\frac{1}{32}$ in. smaller. Six pins *A* to fit this smaller hole are fitted to the fixture and accurately positioned.

The work is located on the spigot *B*, which is keyed to the adaptor plate *C*, and by the pins *A*, each of which locates in the reamed hole in turn. The first keyway or splineway is cut, the component is then removed and indexed, and another splineway cut, this operation being continued until six splineways have been cut, completing the job. Since the pins in the fixture are smaller than the other five holes in the component, no interference takes place.

Outrigger Supports for Broach

Difficulty is often experienced on the horizontal type of machine in keeping the broached bore concentric with the outside diameter of the component, because the overhang of the broach tends to give it a downward bias. This effect is not detrimental when the broaching operation is followed by finishing operations which enable such errors to be rectified. On the component shown in Fig. 7, however, it was necessary to leave the bore soft and to perform the splining operation after finish grinding the outside diameter and just prior to grinding the tooth profiles. It was required that the broached hole be truly concentric with the teeth on the periphery, to even up the grinding allowance on the teeth. For this reason, the seemingly rather elaborate fixture was designed, and has proved very successful in use.

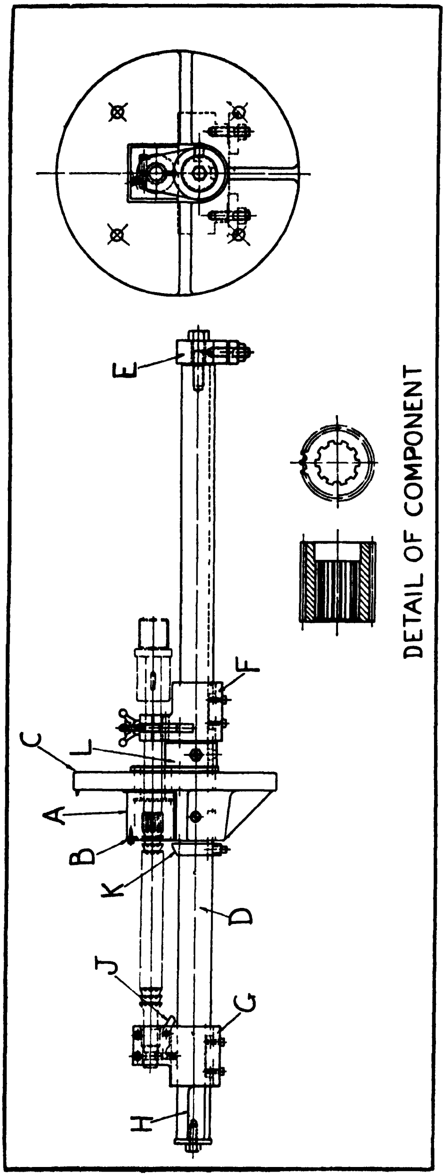


Fig. 7.—Fixture with Outrigger Supports

In the first operation the component is roughed out from a bar and a service hole is drilled and reamed ·020 in. smaller in diameter than the root diameter of the splines. From this hole all the machining operations prior to broaching the splines are located. Two broaches are used in conjunction with this fixture, and the second or finishing broach is shown in position. The outside diameter of the component having been ground to a close tolerance, it is located in the hardened bush *A* and is prevented from rotating therein by the key *B*, which fits one of the spaces between the teeth. Bush *A* is a drive fit in the body *C* of the fixture, which is spigoted to the machine table.

Fastened through the fixture body is a guide bar *D*, the inner end of which is steadied by the bracket *E*, which is fitted to the frame of the machine. Sliding on the guide bar are two brackets *F* and *G*, which are prevented from radial movement by keys running in a keyway on the guide bar. Bracket *G* when in the extreme outward position is permitted to rotate through 90° by the slot *H*, in order to allow the broach to be inserted through the fixture.

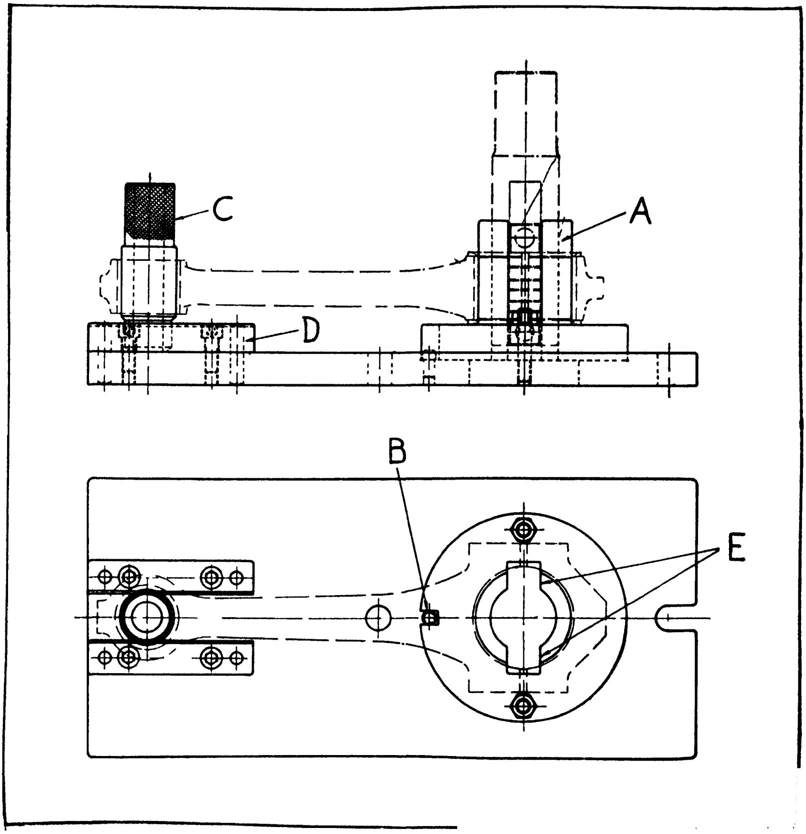


Fig. 8.—FIXTURE FOR PUSH BROACHING

The fixture is shown in a position where it has just been loaded and is ready for the cut to commence. The front of the broach is clamped in the bracket *F* and the rear is located in a hardened bush in the other bracket *G*. As the broach traverses through the work the two brackets are carried along with it and serve to maintain accurate alignment. When the last tooth of the broach is about to enter the work, the trigger *J* on bracket *G* strikes the block *K* and releases the bracket from the broach, allowing it to pass through the work. On completion of the cut, the latch on bracket *F* is released and the broach can be removed and a brass block *L* is fitted to the guide bar in order that the broach teeth may not be damaged on the hardened fixture when releasing the latch.

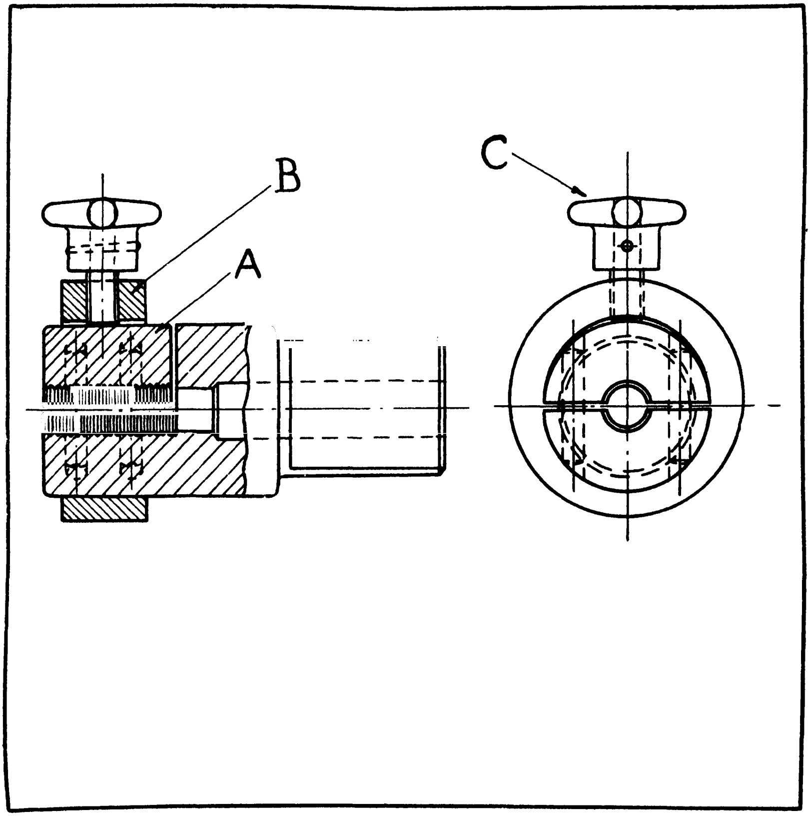


Fig. 9.—PULLER FOR SMALL BROACHES

Fixture for Push Broaching

The fixture shown in Fig. 8 is for use with the push broach shown in Fig. 10, page 215. The fixture is used for broaching clearance slots in the main bores of connecting rods, and is adaptable for rods having varying sizes of bore and of different lengths. For this reason the spigot *A* locating in the bore of the component is made readily removable, being held by two nuts and studs and located radially by the pin *B*, which fits a slot in the spigot. The other end of the component is located by inserting a plug *C* in the bore, which plug is reduced on its front end to fit between two hardened blocks *D*. The length of these blocks is such that rods of various lengths can be accommodated. The bore of spigot *A* is made such that the broach insert holder is a sliding fit therein. Since the radial

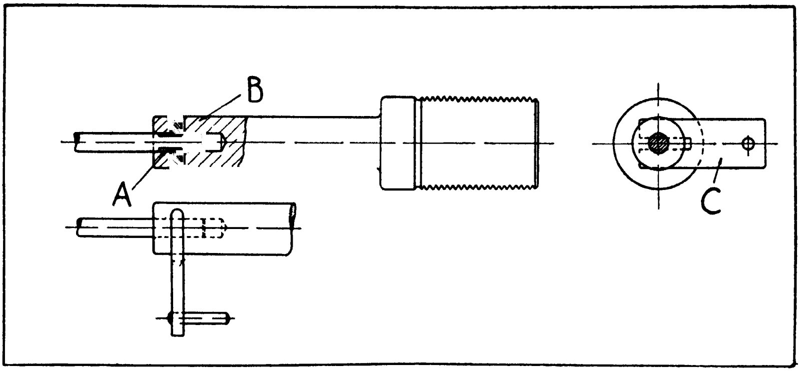


Fig. 10.—PULLER FOR SMALL BROACHES

disposition of the slots in the bore of the component is not important, the two slots *E* in the spigot are made to clear the broach inserts and no positive means of lining up is provided, it being sufficient to line the broach up by eye with the clearance slots.

Fixtures for Surface Broaching

Three conditions are essential for successful surface broaching :

(1) The amount of stock to be removed by the broach must be consistent and controlled within reasonably close limits.

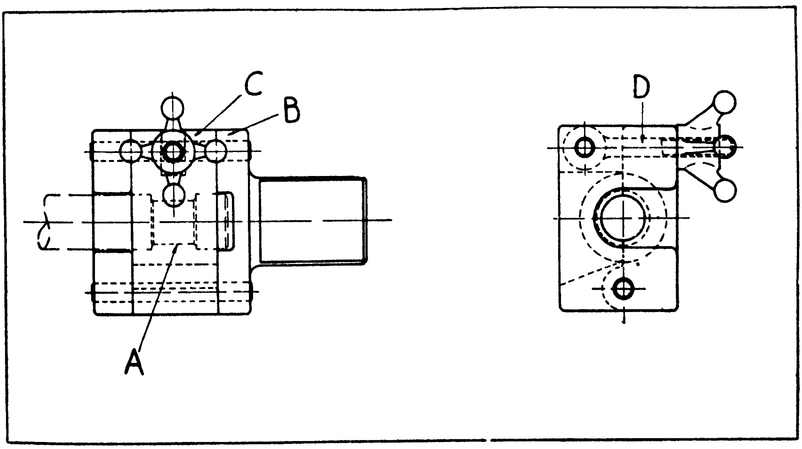


Fig. 11.—PULLER FOR LARGE BROACHES

(2) Workpiece must be strong enough in itself to withstand the considerable broaching stresses which will be introduced.

(3) Workpiece must be of such a shape that it can be firmly held in a fixture and well " backed up " against the cut.

Many of the principles given in the chapter on " Milling Fixtures " may be applied to the design of fixtures for surface broaching. It must be borne in mind, however, that the fixtures must be at least as, if not more, rigidly constructed.

To a greater extent than when milling, loading times will absorb a larger proportion of the machining cycle. Full advantage must therefore be taken of rapid yet substantial clamping devices.

Broach Pullers

Broaching machines which work on an automatic cycle have the broach-pulling arrangements integral with them, and the pulling cotter is fed through the broach at the appropriate time. Each machine usually has several standard sizes of broach socket, these being changed to suit the size of broach in use. Following are several representative types of broach puller which are used on non-automatic machines. Fig. 9 shows a pattern in common use with keyway broaches which are too small in section to be slotted or cottered. The end of the broach is threaded as shown in Fig. 4, page 209, and the puller is threaded to suit. Part of the puller is cut away to form a loose cap *A*, which is located by pins and held in place by a loose collar *B*, having a clamp screw *C*.

Fig. 10 shows another type of puller suitable for small broaches. Two flats are ground on the broach shank at *A*, and the shank is made a push fit in the body *B* of the puller. The pull of the machine is transmitted by a forked plate *C*, which straddles the flats on the broach shank and drops into two slots in the puller body. The large thread on the puller is to fit the ram of the broaching machine.

In Fig. 11 is shown a puller suitable for larger broaches which permit a groove *A* being cut in the shank. The machine pull is taken on a collar turned half in the puller body *B* and half in the latch *C*. This latch is locked by a swing bolt *D*, which is tightened by the hand nut shown. The width of the latch should be made a good sliding fit in the body of the puller.

When designing a broach puller, the load on the appropriate broach should be checked against the various sections of the puller in order to see that no weakness occurs. The weakest section of the puller usually occurs where the cotter or pulling key is fitted. The strength of the actual cotter should also be carefully checked.

Chapter XVI

GRINDING FIXTURES

WITH certain provisions, grinding fixtures follow along much the same lines as many of the fixtures described in previous chapters, but are perhaps even more diversified in character. The main differences of type can be classified under the following headings :

(1) Cylindrical Grinding :
 Internal, external, and facing.

(2) Surface Grinding :
 Straight-through grinding and revolving table, including the ring grinder.

(3) Gear Grinding.

(4) Hand Grinding :
 Disc grinding and grinding with portable tools.

The following few examples show the general trend of fixtures for these operations, and deal mainly with the first two of the above groups. The third group—Gear Grinding—requires very little in the way of special fixtures, all that is necessary being the provision of mandrels to suit the work. Similarly, the fourth group—Hand Grinding—does not, as a rule, call for special fixtures, except on certain classes of disc-grinding work, where holders are provided for small components in order to protect the operator's hand.

Cylindrical Grinding

On fixtures required for cylindrical grinding work, the following points should be carefully watched :

(*a*) Fixtures should be light but rigid.

(*b*) Fixtures must be balanced as accurately as possible—with the component in position.

(*c*) Means must be provided for setting the fixture truly concentric on the machine.

(*d*) Allow for coolant to be supplied to the grinding wheel whilst in position in the fixture. The coolant can often be fed through the work spindle of the machine by drilling a hole in the centre of the fixture.

(*e*) Avoid, as far as possible, having projections from a revolving fixture. An endeavour should be made to allow the regular machine guard to be brought into use when the fixture is loaded. Failing this, it may be necessary to provide a special guard.

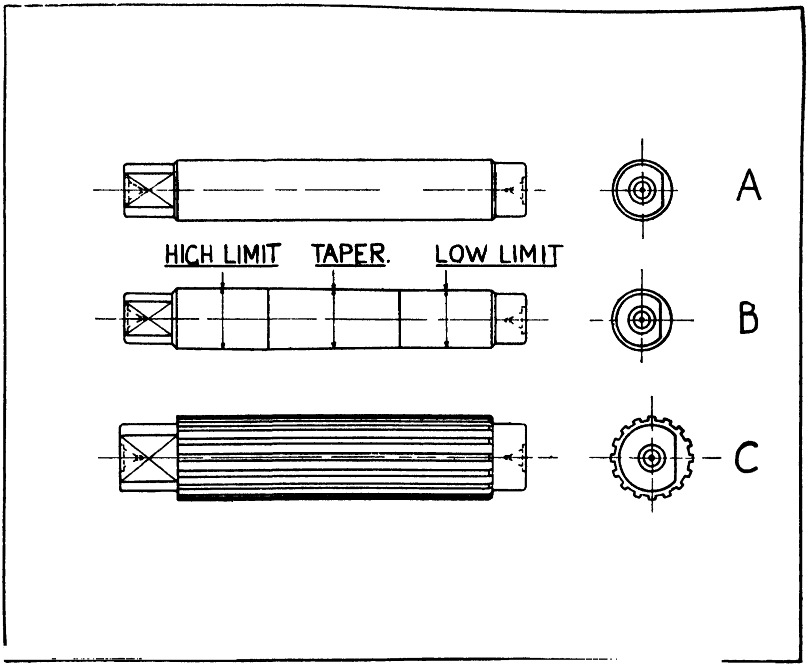


Fig. 1.—TAPER GRINDING MANDRELS

Mandrels

Many external grinding operations can be satisfactorily performed on mandrels. Although not recommended for regular production work, the standard type of taper mandrel shown at *A* in Fig. 1 is very useful for small batches and single jobs. The taper varies from ·0005 in. to ·001 in. on the diameter per inch of length. The smaller amount is better in use, but where a series of such mandrels is stocked it is more usual to work to the larger figure, in order to cover greater variations in the hole diameter.

It will be realised that for these mandrels to grip the work there must be a certain amount of displacement in the bore. For this reason, when used with components of hard material the mandrels should be ground with the small taper, since hard material will not distort so readily. The driving flat is cut on the large end of the mandrel, this feature serving to distinguish the two ends, and is also convenient for the driving carrier.

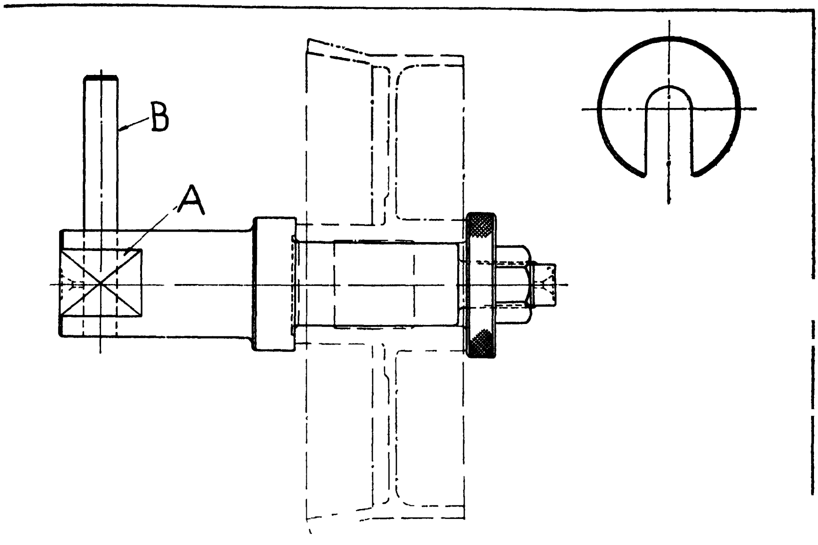


Fig. 2.—PLAIN GRINDING MANDREL

Improved Form of Taper Mandrel

An improved form of taper mandrel is as shown at *B* in Fig. 1. One end of this is made to the low limit of the hole size and the other end to the high limit. The central portion is made to taper between the two diameters. By grinding the mandrel thus a certain degree of parallel location is obtained on most components. A taper mandrel for a splined hole is shown at *C* in Fig. 1. The mandrel locates the component on its outside diameter only, and is therefore not tapered on the splines. The splines cut in the mandrel are made to clear those in the bore of the component, the mandrel, in effect, acting as a plain taper mandrel. It will be appreciated that such a mandrel is only necessary when it is essential to locate on the large diameter of the spline, that is, when this diameter has a finer tolerance than the bore. If it is possible to locate in the bore, then a plain parallel mandrel may be used.

Parallel Mandrel

A type of mandrel which is much easier to use than those described above is that shown in Fig. 2. The component is located on a parallel portion and is clamped against a shoulder by the nut and C-washer. Two flats are milled at *A* to allow the mandrel to be clamped in a vice for loading, and a driving pin *B* is fitted to obviate the need for using a

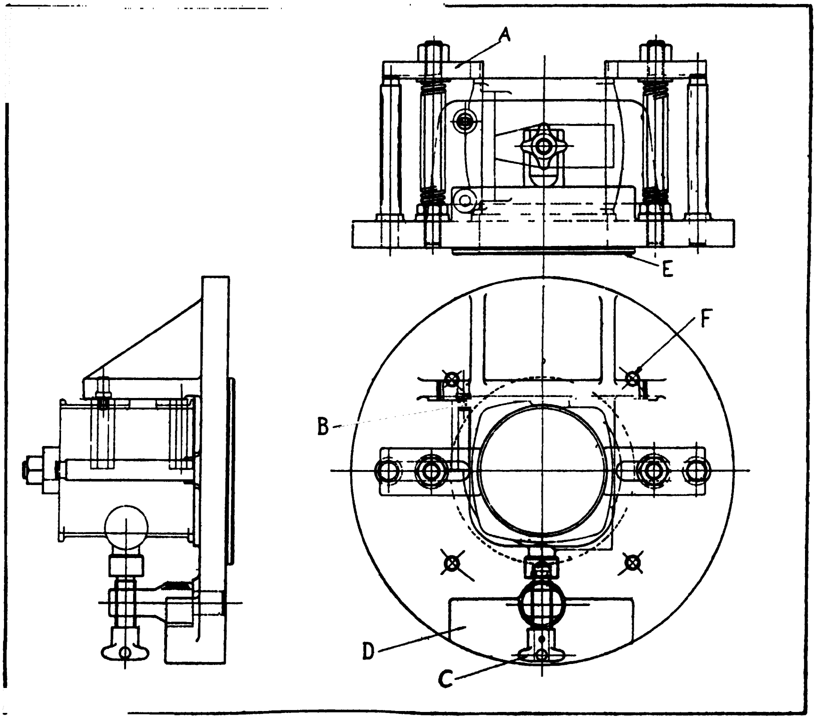


Fig. 3.—Internal grinding fixture

carrier. Such mandrels are not as adaptable as taper mandrels and require to be made specially for each particular component. For this reason the size of the batch must be sufficient to warrant the expense.

Parallel mandrels are more suitable for long components than taper mandrels, since it is difficult to obtain a reliable location with a taper mandrel in a long bore. A parallel mandrel can be relieved along part of its length to provide a location at each end of the bore of the component.

It is often a time-saving proposition to provide two mandrels for a job, to enable the operator to be loading one while the other is in the machine. All mandrels must have their ends accurately centred, and the centres should be recessed as shown in the examples to avoid bruising. When it is required that accuracy is to be maintained over a long period, or where a mandrel is subjected to heavy loads on the centres, it is sometimes the practice to make the centres in the form of hardened inserts, which are pressed into recesses in the ends of the mandrel.

Fixtures for Internal Grinding

In Fig. 3 is seen a fixture for grinding the bore of a cast-iron cylinder of a rather fragile nature. It is essential in this operation that the ground bore is at right angles to the end faces, which have been previously machined parallel. Therefore one of these faces is clamped to the fixture by the two clamps *A*. Lateral location is obtained from a hardened pin *B*, which fits into one of three boltholes drilled in the base of the component in an earlier operation. Before the clamps *A* are finally tightened down, the base of the component is clamped lightly against the vertical wall of the fixture by the hand clamp *C*. This clamp is not powerful enough either to distort the component or to control its location, the final location being on the end face when the clamps *A* are tightened.

This feature is important, because at this stage it cannot be guaranteed that the end faces and the base of the component are at right angles. The base is surface ground in a later operation to bring it true with the bore, and the fixture for this is shown later in this section. A balance weight is cast on the faceplate of the fixture at *D*, and is machined away to give correct balance with the component in position. Since the base of this component is surface ground true with the bore in a later operation, it is not necessary that this fixture is located dead accurately on the machine.

For this reason the spigot *E* is turned on the faceplate of the fixture and provides a sufficiently accurate location for the operation of grinding the bore. The fixture is secured to the machine faceplate by four bolts in holes *F*. When it is necessary that a grinding operation be dead true from a certain location, a register is not be to relied on, and another means must be adopted of ensuring accuracy when setting the fixture on the machine.

Obtaining Accuracy when Setting Up

A useful method of obtaining accuracy when setting up is adopted in the fixture shown in Fig. 4. In this case no register or spigot is provided, but a groove *A* is turned in the faceplate of the fixture. On some fixtures it assists the operator when setting up the fixture if a spigot is provided to locate in the machine faceplate, but allowing about ·005 in. shake or side play. The fixture may then be located roughly by the spigot and finally trued up off the groove. The groove is truly concentric with the register which locates the component in the front plate *B* of the fixture. The fixture is bolted to the faceplate of the machine sufficiently tightly to allow it to be tapped true, after which the bolts are tightened up.

The true running of the fixture is checked by rotating the machine spindle by hand and using a dial indicator in the groove. The purpose of the groove is to protect the checking diameter from damage when handling the fixture, which would probably occur if the outside diameter of the fixture was relied upon. This fixture is for grinding the bore of a

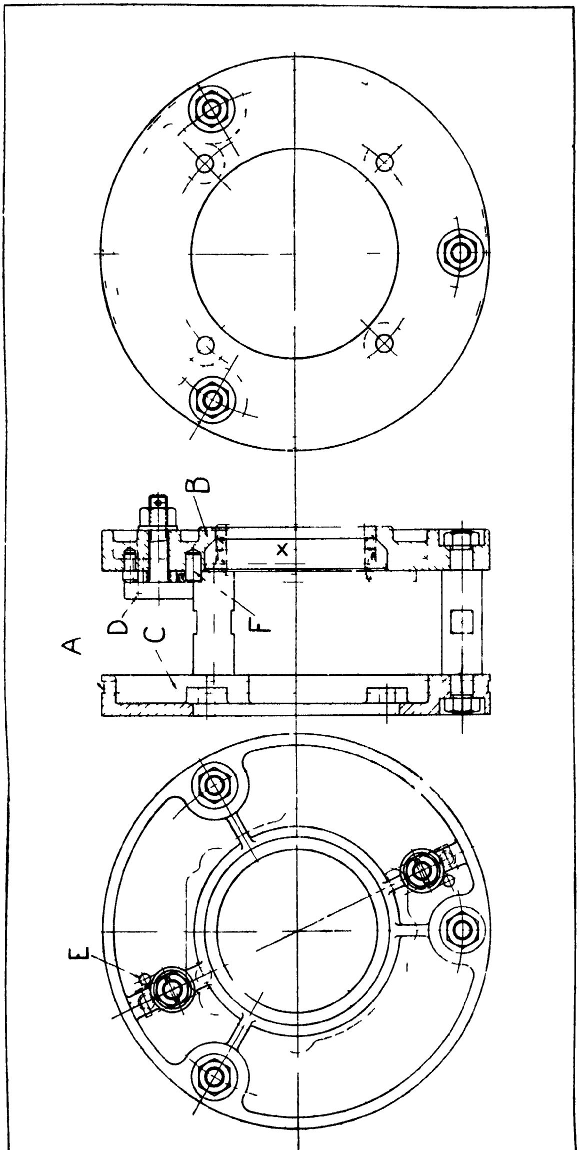


Fig 4.—Fixture for grinding bore
Locating on outside diameter of component.

ball-race housing, and it is necessary that the location is taken from the diameter " X " which has been ground previously.

For this reason the fixture is made in the form of two plates *B* and *C*, held together by shouldered pillars. This enables the component to be loaded into the back of plate *B*, and sufficient room has been left between the two plates for the operator's hands. Two clamps *D* are provided, which are tightened from the front of the fixture and are limited in their rotational movement by the pins *E*. Another pin *F* is fitted, which is an easy fit into one of the holes drilled in the flange of the component, and serves to drive it against the cut.

Pitch-line Fixtures

When producing gears with ground form on the teeth it is usual, after hardening, to grind the bore of the component and then work off the bore for grinding the teeth. In such cases care must be taken to grind the bore as nearly concentric with the pitch line of the teeth as possible, in order to even up the grinding allowance on the teeth. The fixture shown in Fig. 5 is designed for grinding the bores of hardened gears and is arranged to locate off the pitch circle of the gear by the use of three rollers *A*, which are hardened and ground and fit between the teeth. The rollers are made of such a diameter that they each touch the two tooth flanks, and also a block *B*, to which they are loosely attached by keep plates *C*.

An interesting point of construction is raised in fitting the blocks *C*. It is necessary, in order to maintain the accuracy required, that the blocks are finally ground in the bore when assembled to the fixture. To allow for this the inner keep plate is stepped as shown in order that the grinding wheel may be fed right through the block and avoid leaving a ridge.

The fixture consists of a body *D*, to which is screwed and spigoted an adaptor *E*, which is bored to fit the spindle nose of the machine. Fitting inside the body and located at its inner end by a register on the adaptor plate is a split collet *F* of cast iron. The resilience of the collet is increased by a ring of steel, which is split and spring tempered in the manner of a piston ring, and is fitted into a groove in the collet at *G*. The collet is operated by a pull rod *H*, screwed into a plate *J*, which is fastened to its inner face. A handwheel *K* is provided on the back end of the machine spindle for operating the collet. The pull rod is made hollow, and provision is made for fitting a gland at its rear end to enable grinding coolant to be fed through the machine spindle. The component is butted up against the spider *L* in order that the operator may insert it squarely into the fixture and also to take the thrust of the cut. Quite a small movement of the handwheel is enough to close the collet sufficiently to grip the component firmly. The rollers *A*, blocks *B*, together with the keep plates and spider *L*, are made interchangeable for various components, although it is not always necessary to change the spider.

It will be realised that, although in the illustration the three rollers are

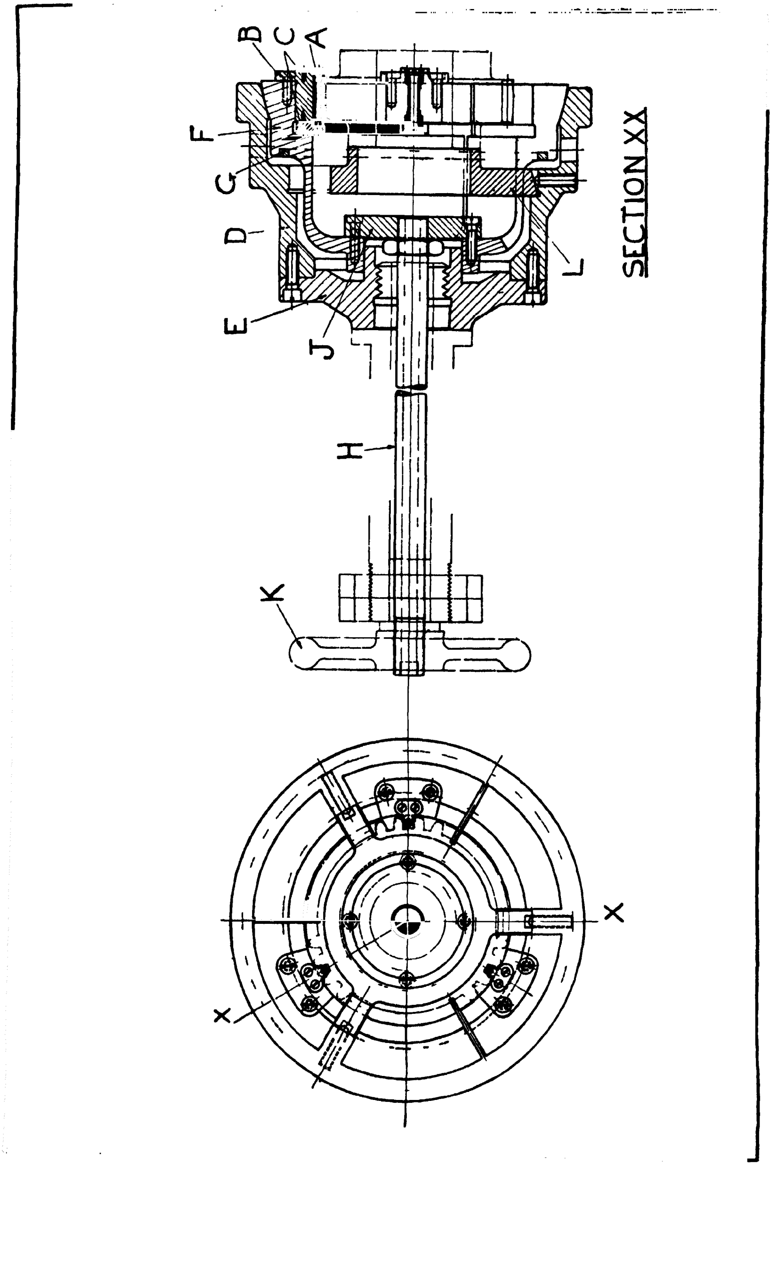


Fig. 5.—Pitch line grinding fixture

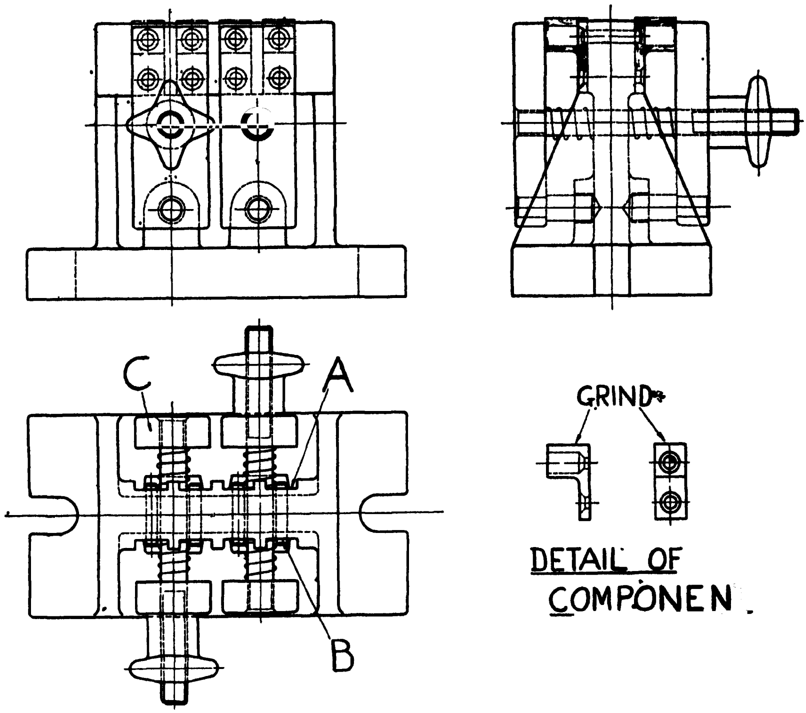


Fig. 6.—Fixture for grinding end faces of component

shown equally spaced, it is sometimes necessary to have them offset from the centres of the blocks to cater for components on which the number of teeth is not divisible by three, in which cases they are spaced as nearly equal as possible.

Fixtures for Surface Grinding

Many surface-grinding operations may be carried out on magnetic chucks, and most surface-grinding machines are equipped with one. Nevertheless, many components cannot be held in this way, and fixtures are necessary. No special rules are required for the design of such fixtures, except to avoid corners which become swarf traps, and the fixtures follow closely those designed for other tooling operations.

In Fig. 6 is seen a simple fixture for grinding the end face of the component shown in the detail drawing. The fixture accommodates eight components at one loading, location being in slots *A* to suit the width of the work and end location being provided by pins *B*, which fit drilled

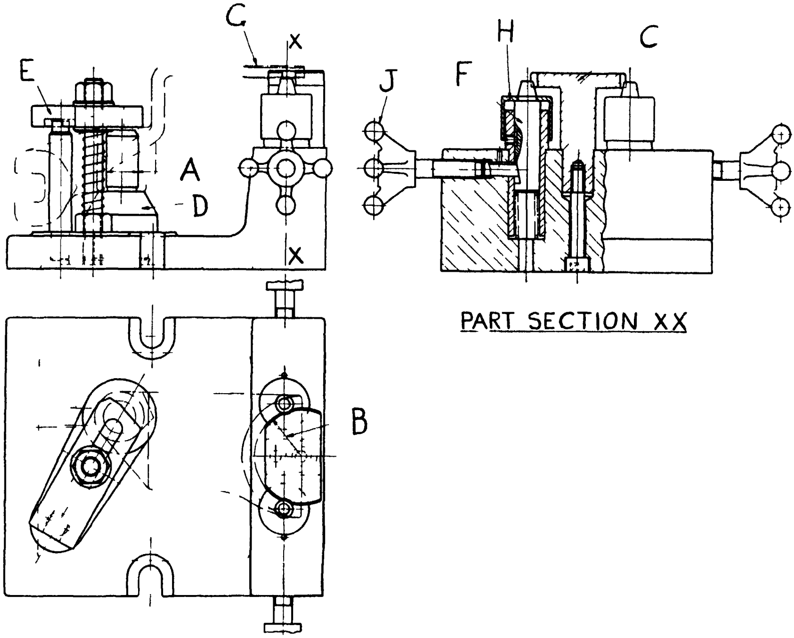


Fig. 7.—FIXTURE FOR GRINDING FACE TRUE WITH BORE OF COMPONENT

holes in the component. Four clamps *C* are fitted and are operated in pairs by two studs, which pass through the body of the fixture. The hand-knobs are placed on opposite sides of the fixture to avoid fouling. The clamps are spring loaded, so that when the handknobs are loosened the clamps clear the fixture for loading the components.

Fig. 7 shows a fixture for a more awkward component. The operation is that of grinding the face marked *G*, which is required to be true with the bore *A*. Radial location is taken from the radius *B*, which fits a plug *C*. Bore *A* is fitted on to a pin *D*, where it is held by an ordinary strap clamp shown at *E*. The thrust of the cut is supported by two jacks *F*, which are spring loaded against the underside of the component and finally locked in position by the handknobs *J*. The jacks are fitted with thimbles *H*, which prevent the ingress of swarf and dirt.

The fixture shown in Fig. 8 is for grinding the foot of the same component as that in Fig. 3, in which fixture the bore was ground. The component is located on a spigot *A* in the ground bore and held in place by a quick-release washer *B*. Rotation of the component on the spigot is prevented by an adjustable jack.

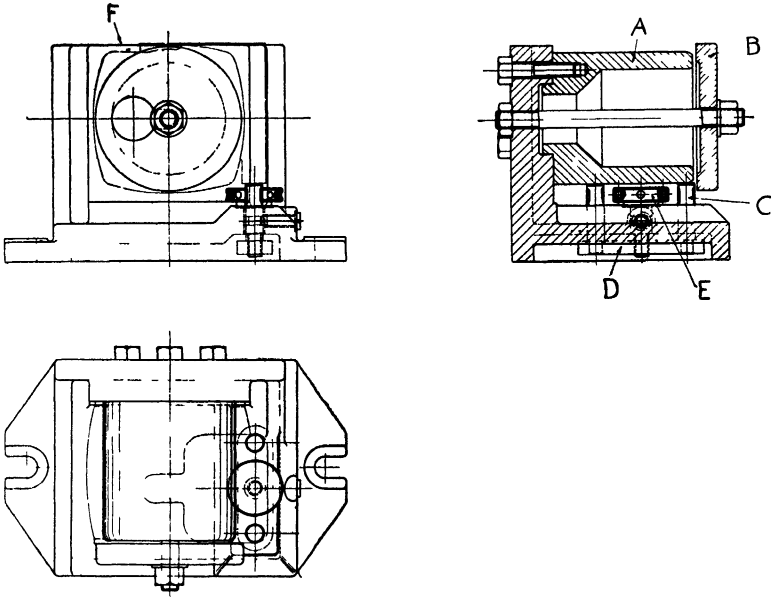


Fig. 8.—FIXTURE FOR GRINDING FOOT OF COMPONENT

This consists of two pins *C* riveted to a bar *D*, which is raised or lowered by the screw *E*, the head of which is drilled with tommy holes. The dimension for grinding the foot of the component is given from the centre line of the bore and is required to a close tolerance. To assist the operator to set the grinding wheel to the correct height, the top face *F* of the fixture is made to a known figure from the centre of the spigot, thus providing the operator with a gauging face. A small plate gauge is included with the fixture for checking the height of the ground face.

Ring Grinding

Ring grinders are for the most part fitted with a revolving magnetic chuck, which may be used for grinding rings, flat plates, or any components on which the chuck may be used effectively. When it is required to grind small components, a simple fixture, such as that shown in Fig. 9, proves very useful. This fixture is for grinding the heads of the bushes shown in position, and consists of a cast-iron ring in which is bored a circle of holes to take twelve components at one setting. These holes are fitted with steel bushes to provide a more lasting location. The fixture is held on a magnetic chuck, and it will be noticed that the heads of the component clear the fixture, in order that the ends of the components seat

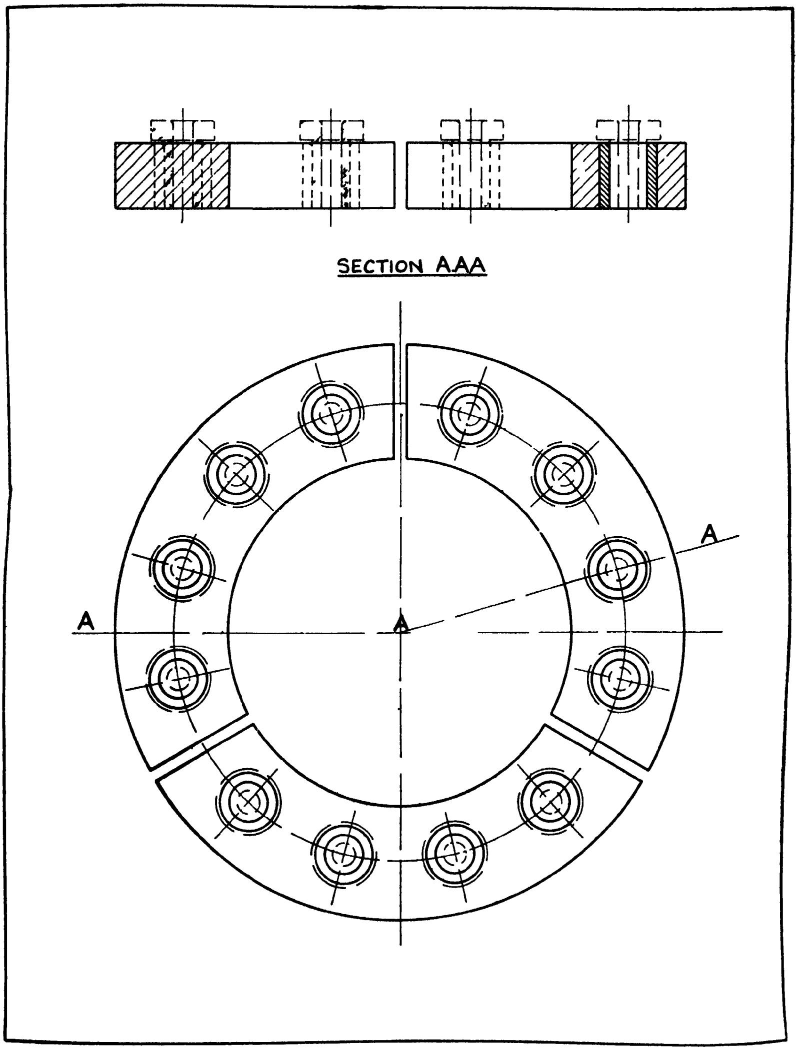


Fig. 9.—FIXTURE FOR GRINDING BUSH HEADS

right down on to the chuck to obtain an effective hold. The fixture is split into three sections, as shown, to assist in removing it from the magnetic chuck when the current is switched off. If such rings are left in one piece, great difficulty is experienced in removing them, due to magnetism remaining in the fixture.

A point to be watched when designing fixtures of this nature is the position of the poles on the magnetic chuck, and it is sometimes necessary to space the components in the fixture to suit these positions and so obtain sufficient holding power.

Chapter XVII

GRINDING-WHEEL TRUING DEVICES

IT is essential, on any grinding operation, that the grinding wheel is dressed or trued after being mounted in the machine. Further, it is necessary that some means is provided on the machine for periodically re-truing the wheel. The frequency with which this operation is carried out depends on the nature of the material being ground and the accuracy to be maintained on the finished work. In any case, fairly frequent re-truing of the wheel results in maintenance of good cutting qualities and improved finish on the work.

Grinding-wheel truing is carried out by the use of commercial-quality diamonds, which are mounted in holders for convenience of handling.

Most production grinding machines are fitted with devices for truing plain grinding wheels on their diameters and sometimes on their side faces. On some machines the wheels are trued automatically as part of the cycle of operations, and the consequent reduction in size of wheel is compensated by the truing mechanism.

When form-grinding operations are being considered, however, it becomes necessary to design a special wheel-truing device. The problems involved on such occasions are many, but the following examples will serve as a guide to the designer and can be relied upon, as each and all have proved successful in operation. The most important features in all wheel-forming or truing devices are smoothness of action and absence of chatter.

Forming a Radius

It is sometimes necessary to dress a wheel for grinding a radius, and the device shown in Fig. 1 is designed for this purpose. The diamond is carried in a holder *A*, which is fitted into a rotating member *B* and held by a setscrew. The member *B* is made a good running fit in the block *C* and has a taper shoulder ground at *D*, which fits a similar taper in the block and serves to keep out dust. Two locknuts *E* are fitted for the purpose of taking up end play. Provision is made for oiling the bearing by removing the screw *F*. The tenons *G* are for lining the attachment up on the machine table. Any radius may be dressed up to the radius of the member *B* by varying the setting of the diamond holder.

Forming an Angle

The attachment shown in Fig. 2 is for dressing a wheel at an angle θ. The diamond holder is clamped into a plunger *B*, which slides in a hardened

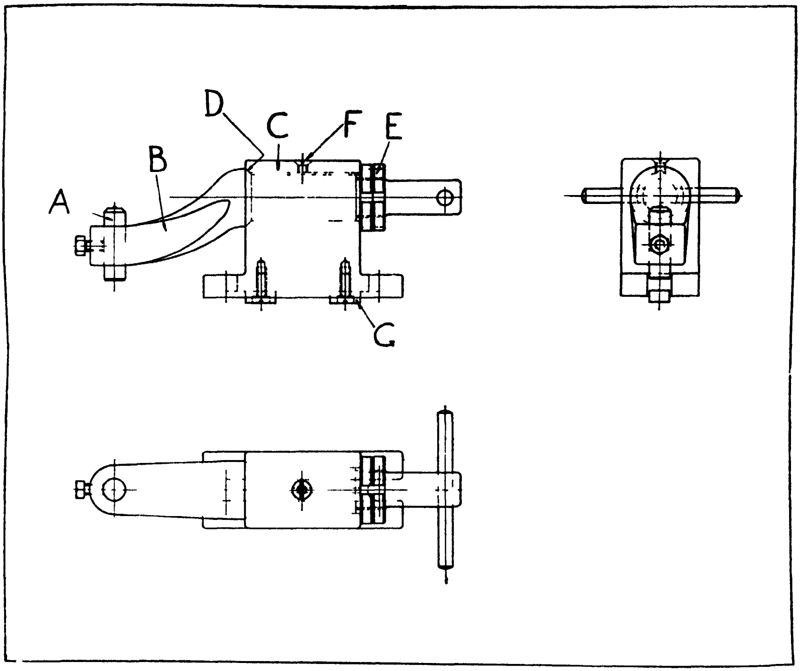


Fig. 1.—DEVICE FOR FORMING A RADIUS

bush *C* held to the cast-iron body *D* by a mild steel cap *E*. The plunger is oscillated by the hand lever *F* through the link motion and is retained in its upward position by a spring. The movement is limited by a sleeve *G*. This attachment could be simplified, if desired, by omitting the lever and link motion and fitting a handknob direct on to the end of the plunger, although the action would not then be so smooth, as there would be no mechanical advantage such as is provided by the link motion.

Spline Grinding

In Fig. 3 is shown an attachment carrying three diamonds for truing the angular sides and the root radius of a wheel for grinding splines. The use of such an attachment enables the wheel to be trued sufficiently accurately to grind the spline in one operation with a wheel formed to the shape of the complete splineway. The body *A* of the fixture is cut from a block of mild steel. Running in the block is a spindle *B*, which is oscillated by hand and carries the diamond holder *C* which generates the

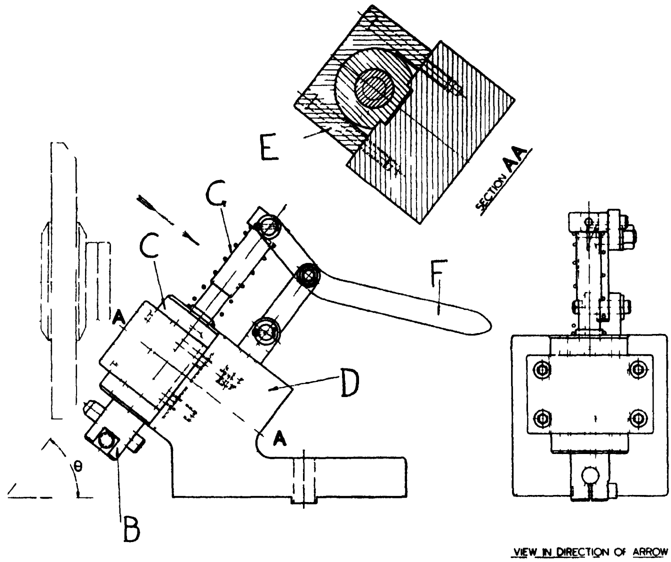


Fig. 2.—DEVICE FOR FORMING AN ANGLE

root radius on the grinding wheel. The diamond holders *D* for truing the sides of the wheel are carried in two blocks *E*, which are mounted on saddles *F*. These saddles are arranged to slide on the brackets *G* along the dovetail slides shown in the part-sectional view. The brackets are spigoted to the body and pivot about the centre of the spigot to allow for variation in the angle of the spline. Their movement is limited by the movement of the stud *H* in the radial slot, and they are secured in position by a nut on this stud. The attachment shown in the example is arranged for dressing wheels with included angles of from 15° to 104°.

In order to assist in setting the required angles, the circular periphery of the brackets *G* is graduated in degrees, and two index blocks *J* are fitted, which are each marked with a zero line. The final setting of the diamonds is accomplished by fitting a setting gauge into the slot on the top of the fixture.

An example of such a gauge is shown in Fig. 4 and is a replica of the

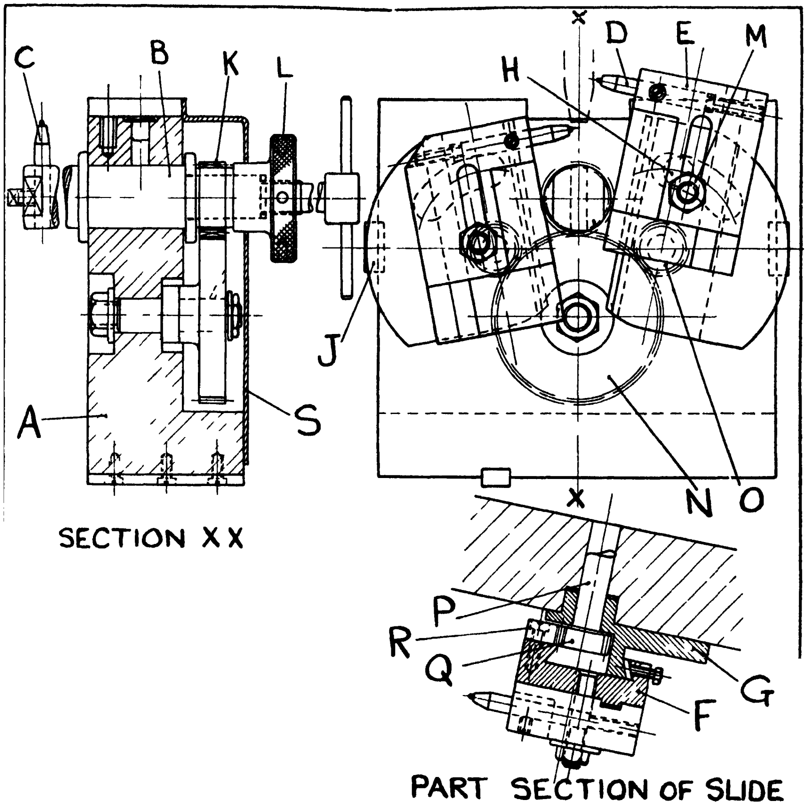


Fig. 3.—Truing device for use when grinding splines

splineway to be ground. Care has to be taken in the manufacture of these gauges that they are in correct relative position, when fitted to the attachment, with the centre of spindle *B*, which, in effect, is the centre of the shaft to be ground.

A pinion *K* is fitted to spindle *B* and is held friction tight thereon by the nut *L* to permit adjustment of the diamond holder *C* in relation to the other holders *D*. These latter are adjustable in relation to one another by loosening the nuts *M* and sliding the blocks *E* along the saddles *F*, alignment being maintained by the two tongues shown. Pinion *K* drives a gear *N*, which in turn drives two pinions *O* keyed to shafts *P*, whose centres are coincident with the pivoting points of the brackets *G*. On the other end of these shafts, and integral with them,

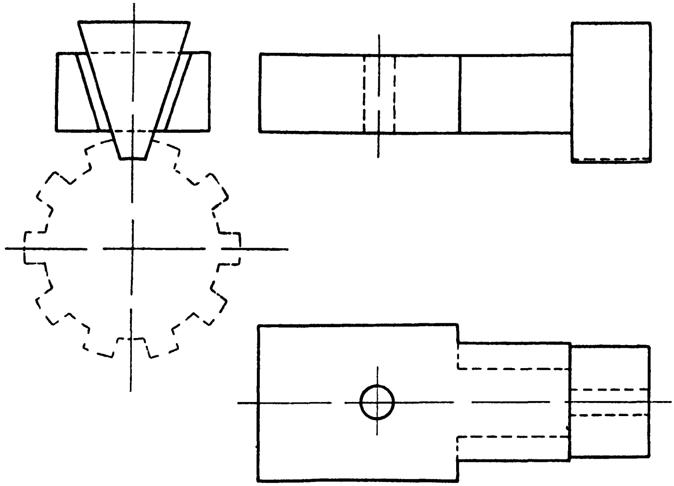


Fig. 4.—Setting gauge for truing device for spline grinding

are pinions *Q*, which engage with racks *R* mounted on the saddles *F*. Thus, when the spindle *B* is oscillated, the two saddles are caused to move up and down on the slides and so allow diamonds *D* to dress the angular sides of the wheel. A guard *S* is fitted over the gears to prevent entry of dust.

The space in which this device is designed to operate is very confined, and for this reason it was not possible to enclose the slides as efficiently as might have been done to prevent entry of dust. Nevertheless, good service is obtained before the slides become so badly worn that they are unreliable in service. In spite of the emery dust, such a fixture has been in fairly regular use for eleven years with biennial overhaul.

Blending Two Radii and a Straight Line

In Fig. 5 is shown a truing device which was designed for producing a wheel form to grind two radii blended one into the other and for dressing the face of the wheel in the same operation. The diamond traverses the required form from the generated profile on the plate *A*, the motion being transferred to the diamond point through the radii at *B* and *C* on a lever which is free to rock at *D*.

The radius at *B* contacts with the sliding member to which the diamond

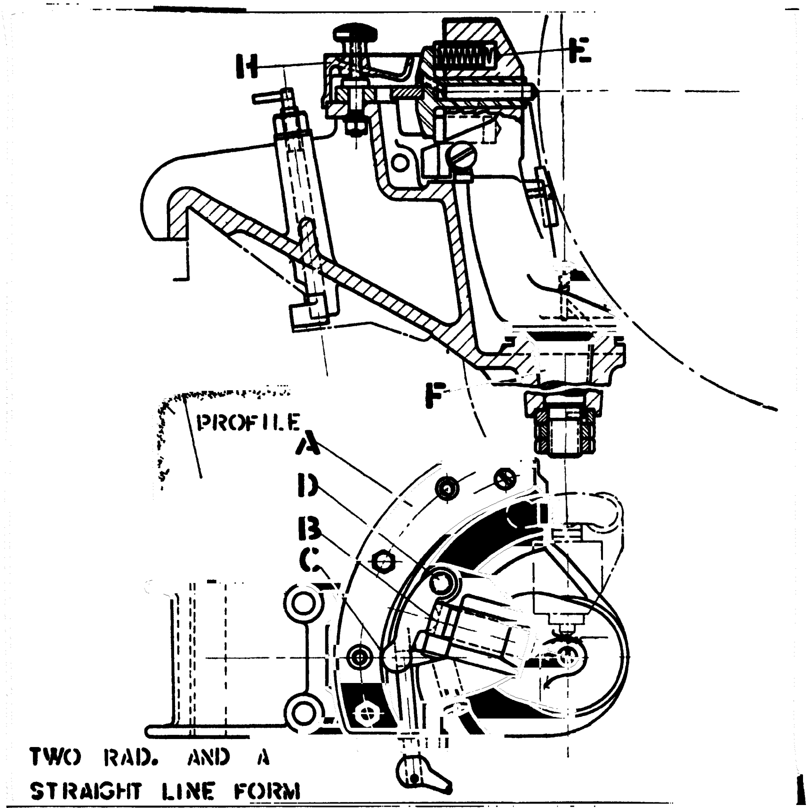


Fig. 5.—DEVICE FOR BLENDING TWO RADII AND A STRAIGHT FORM

is fixed. The rocking lever is kept against the cam plate by the springs at *E*. To generate this form a hardened master, identical with the shape required on the wheel, was set into the required position over the centre pivot *F*, by attaching it to a loose bracket, arrangements for the accommodation of which were made on the fixture.

To generate the master cam the diamond was replaced by a hardened pin. The springs shown at *E* were not fitted, but a slave spring was attached to the rocking lever, thus holding the hardened dummy diamond against the master. As the moving member of the fixture pivoted, arcs were scribed around the radius *C* on the rocking lever, marking a template which at this stage was fitted in place of the former plate. The template was subsequently used as a gauge for making the former plate.

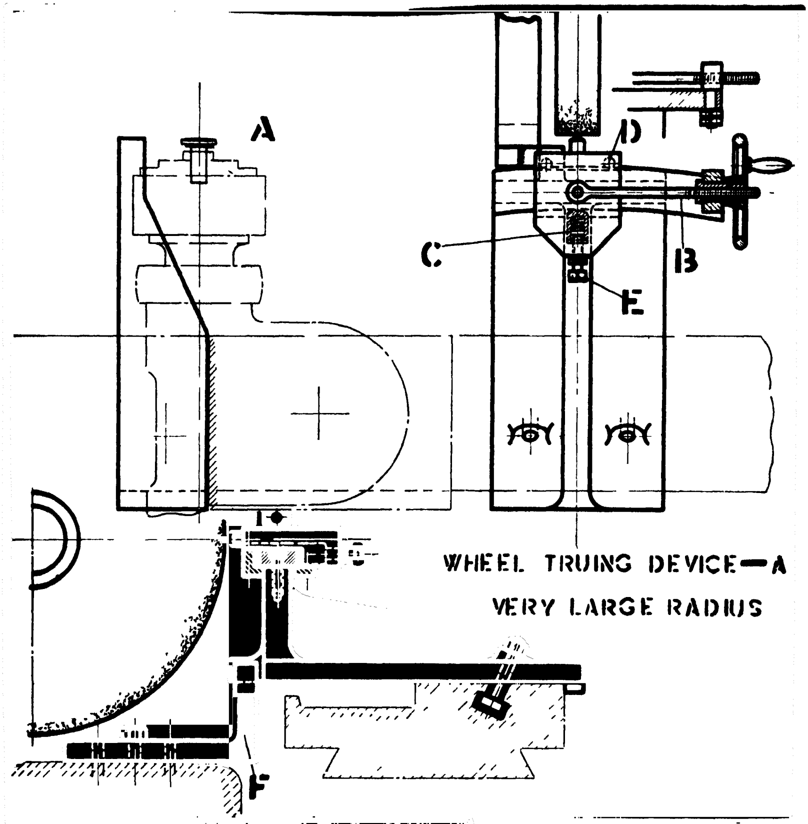


Fig. 6.—Device for truing a large radius

The grinding wheel being 8 in. wide, it is an advantage to be able to true the face with this fixture as well as the form, so that they coincide without leaving a ridge. It was, therefore, impossible to arrange for the movement of the diamond to be obtained from a position immediately in line with the diamond point, because this would place the former plate in such a position as to foul the wheel when truing across the wide face.

It is also of advantage to operate through a lever, because any error in the former plate is reduced through the ratio of the lever.

A stop is fixed to prevent the diamond entering the side of the wheel on the one side, and after the forming of the radii is completed, the diamond is locked in position by a latch and so becomes fixed whilst facing

the wheel diameter. The diamond is set in its relative position by a gauge used on the adjacent face of the pivoting member.

All the small steel parts are made from stainless steel and the pivoted member of bronze, and the whole arrangement is covered in, as far as possible, by the casting *H*.

Truing a Large Radius

Referring to Fig. 6, in the chuck shown at *A* at the top left of the figure is a small hardened component, the head of which has to be form ground to a 6-ft. radius.

The diamond traverses the correct path by turning the handwheel, attached to which is a screwed bush which in its turn moves the link *B*, which pulls or pushes the diamond holder. This holder is spring loaded on to the track through the spring *C* operating against two pins *D*, the flatted surfaces of which seat on the track. The spring tension can be adjusted by the screw *E*.

For convenience when re-diamonding the wheel and to ensure that the centre line of the radius is coincident with the centre line of the work, a stop *F*, against which the attachment can be located, is bolted to the wheel slide.

Truing an Irregular Form

A device which could be developed for truing many irregular forms is shown in Fig. 7.

The path of the diamond on this attachment is controlled by the former shown at *A*, the edge of which nearest to the wheel is an accurate though enlarged replica of the form required on the wheel, the enlargement being necessitated by its distance from the grinding wheel. On the opposite edge of the former, two cam paths are cut, one above the other.

The two rollers, on the rear of the block holding the diamond, follow these paths, which are so formed that the diamond is kept at right angles to the wheel at each position of its cutting, ensuring that the same point on the diamond is being used throughout the whole of the operation. The diamond is held in a sleeve, at the back of which a roller is fitted. This runs against the accurate form.

In order to overcome any error in coincidence between these three cams and rollers, compensation is arranged between the sleeve holding the diamond and the block carrying the sleeve and rollers by the two coil springs, shown in the plan view, which thrust the roller on the diamond holder against the accurate former and operate in the opposite direction on the other two rollers, so holding them on the cam tracks. The arrangement is operated by turning the handle upon the fixture, rotating the gears, the sprocket wheel beneath which travels along the pins in the face of the former after the manner of a chain. A feature of the rest of the attachment is the two slides at right angles to each other, which automatically compensate and allow the diamond holder to traverse the

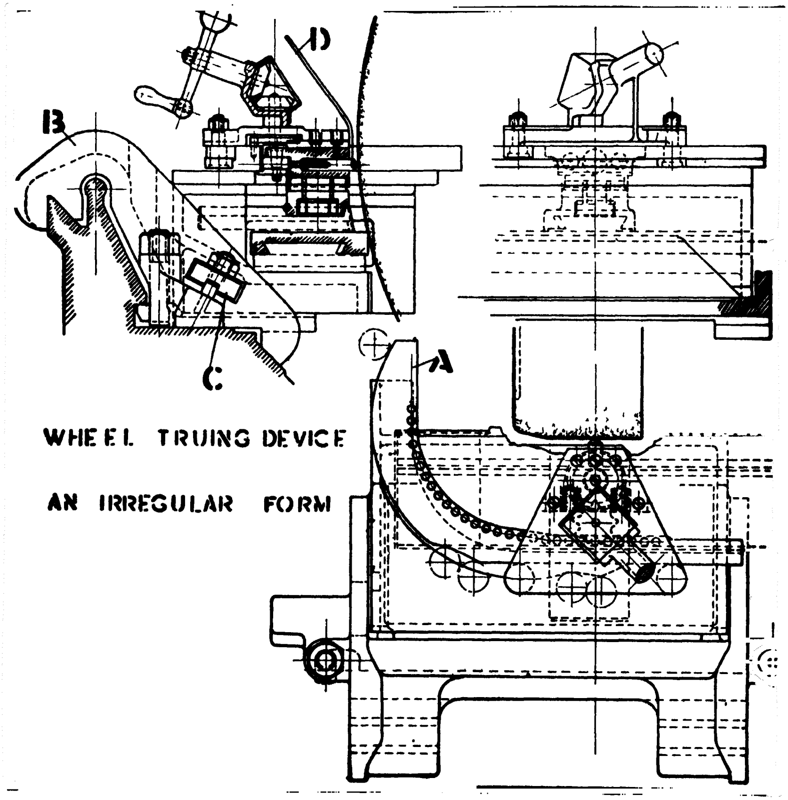


Fig. 7.—TRUING DEVICE FOR AN IRREGULAR FORM

correct form. For quickness of operation, it is arranged that the bracket *B* remains permanently set on the machine, and the rest of the mechanism, being of light construction, can easily be set in position and held by the clamps *C*.

All slides remain covered, and a guard *D* is fitted to keep water away from the parts.

It hasbeen found an advantage on this type of fixture to replace the bevel drive by a worm and worm wheel in order to overcome any tendency for the resultant reaction of the bevels to force the carriage, carrying the diamond, out of position against the springs. Any distortion of this nature nullifies the advantage given by the two cam tracks in maintaining the diamond at right angles to the face being trued.

Single-diamond Grinding-wheel Trimmer

This device, shown in Fig. 8, operates with one simple motion and can be used to trim wheels accurately for form-grinding involute teeth, spline shafts, and special profiles for flute-grinding generally.

It consists of a circular rod, shown at *A*, which is supported by a spring-loaded spherical bearing, on a ball *B* integral with the rod. The spring-loaded bearing is located in a socket *C* which is protected from the ingress of grinding compounds and particles.

On the long end of the rod is secured a rectangular block containing a hardened steel ball *D* acting as a follower on the former plate *E* and kept in contact by a spring-loaded yoke *F*, which follows the yoke plate *G*, thereby keeping the diamond holder *H* radially disposed to the point of contact with the grinding wheel.

The profile of the former plate is reproduced diametrically opposite on the wheel and is a multiple of the form required in a ratio of *J* to *K* from 4 : 1 to 8 : 1, according to the accuracy required. As shown in the illustration, the whole device is enclosed in a casing which also acts as a mounting. This can be cast from light alloy, unless it is intended to use soda water, in which case it should be cast iron.

It is an essential feature of the design that provision is made to allow the diamond point to be adjusted to a line running through the point of contact of the hardened-steel ball *D* on the former and the centre of the ball *B*. To obtain this, a setting gauge *L* is provided. The rod *A* has a flat face which is ground to a predetermined distance *M* from this straight line, and the distance *M* is maintained by means of the gauge. The part of the gauge marked *N* is free to rotate and contains a parallel slot which engages with the square end machined on the diamond holder. The grub screw clamping the diamond holder is slackened before the gauge is applied. The diamond is adjusted for position by turning the knurled adjuster *N*, which serves the dual purpose of acting as a thumb-and-forefinger adjustment for the diamond holder and as a fixed distance-piece masking the square machined on the diamond holder, allowing the fixed dimension *M* to be measured. The adjustment is made only occasionally as a check on diamond wear or when a new diamond is re-set, and is the only adjustment necessary. It is essential that the diamond be set centrally in the copper holder to ensure accuracy of results.

Each former plate used in this device is accompanied by its appropriate yoke plate *G*, which has a form parallel to the former plate, but not to the same degree of accuracy. The two contact pads of the spring-loaded yoke *F*, which slides in a rectangular block, follow the yoke plate. These two pads keep the ball *D* in close contact with the former plate by the action of the spring *P*. The triangle formed by these two pads and the ball control the rod *A* radially and thus ensure that the diamond holder is substantially radial to the form being dressed. This condition

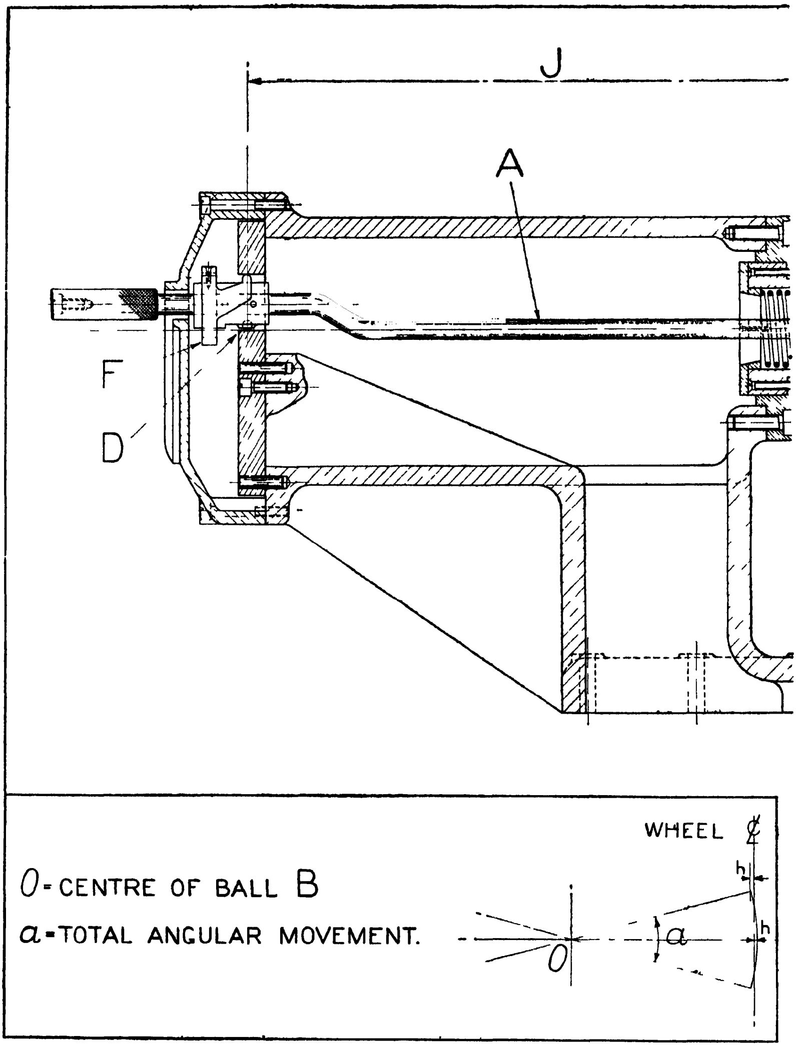
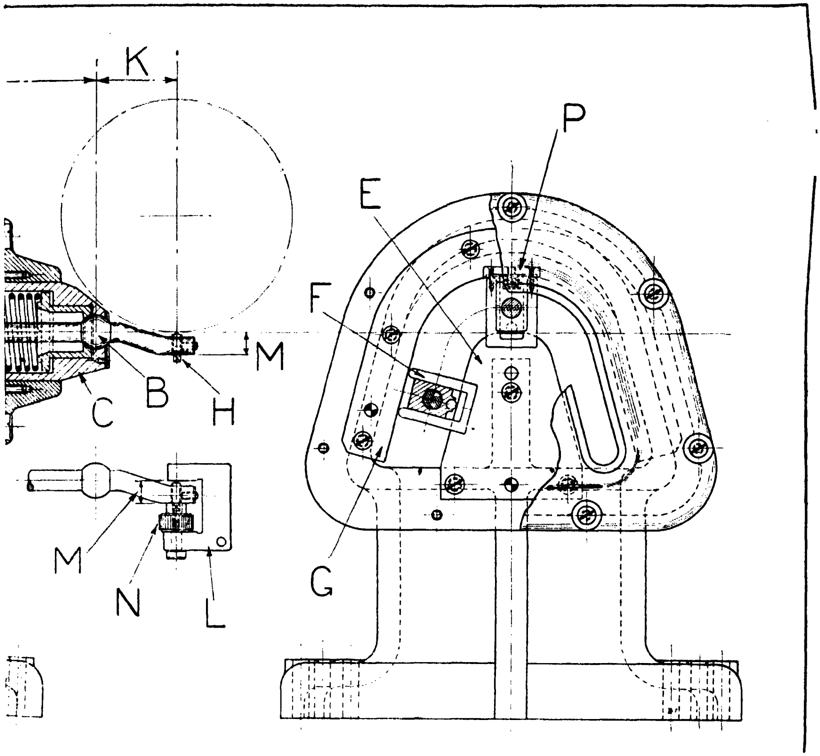


Fig. 8.—SINGLE-DIAMOND GRINDING-WHEEL TRIMMER



A = Circular rod
B = Ball
C = Socket
D = Hardened steel ball
E = Former plate
F = Spring-loaded yoke
G = Yoke plate
H = Diamond holder
L = Setting gauge
N = Adjuster
P = Spring

is not critical, but desirable to maintain accuracy when a small facet is worn on the diamond.

The point of the diamond when dressing traces a curved path with radius *K*, deviation however from the vertical centre-line of the wheel is so small within the angular limits of the device that in practice it has no measurable effect on the form produced on the wheel. The extent of the deviation which occurs is shown as *h* in the inset diagram. For the sake of clarity (with the device as illustrated) the bar is shown in a horizontal position when on the top of the former plate. It should be

noted, however, that when laying out formers the working angular movement should be equalised above and below the horizontal centre-line as shown in the inset (Fig. 8). Therefore, when considering a former for an involute gear the pitch line would correspond to the horizontal position.

In operation, a stop is set on the machine table so that the trimming position is maintained as described. The device should be designed with an operating angle a not exceeding 24°, to obtain the most satisfactory proportioning of the ball and socket. The length of the arm K should be proportioned to suit the length of the profile to be dressed on the wheel.

Chapter XVIII

GRINDING-WHEEL FORM-CRUSHING

THE accurate grinding of various forms can often be more economically carried out by a grinding wheel which has been crushed to the required form by means of a hardened roller, instead of employing the diamond, with its attendant, and often costly, trimming device. Grinding-wheel crushing offers an attractive medium for the form-grinding of the difficult shapes which so often occur on form tools. The method described in this chapter was developed in connection with rectangular-section formed tools. The machine employed is the usual type of light surface grinder.

The Grinding Wheel

The grinding wheel is formed very roughly to the required shape by means of a piece of carborundum or a diamond, by hand. It is then brought into contact with a hardened-steel roller having the required form ground on its periphery, and the grinding wheel is rotated at a steady speed of approximately 60 r.p.m. by means of a temporary handle attached to the grinding-wheel spindle: at the same time it is fed by small increments on to the roller. Small particles of the wheel are thus forced to disintegrate, and are removed from the wheel with the aid of a stiff brush and directed into the exhauster duct, until the required form has been crushed into the wheel.

Electrical Cut-out Device

In the elevation view of the grinding machine, an electrical cut-out device is shown, to obviate the danger of the machine being accidentally started whilst the handle is attached to the grinding-wheel spindle. This takes the form of a bar moving on a pivot which, when raised to allow the handle to be fixed to the spindle, trips a limit switch.

The Crushing Roller

The crushing roller is mounted in a block, which may form part of the work-piece holding device. The illustration shows a simple combined block for mounting the roller and holding the square-shanked turning tools, etc. The work-holding position may be adjusted to grind various clearance angles on the tools, and by setting the tool at an angle on the block, tools can, when necessary, be form-ground at compound angles. The tool is set up according to its profile and the required direction of its

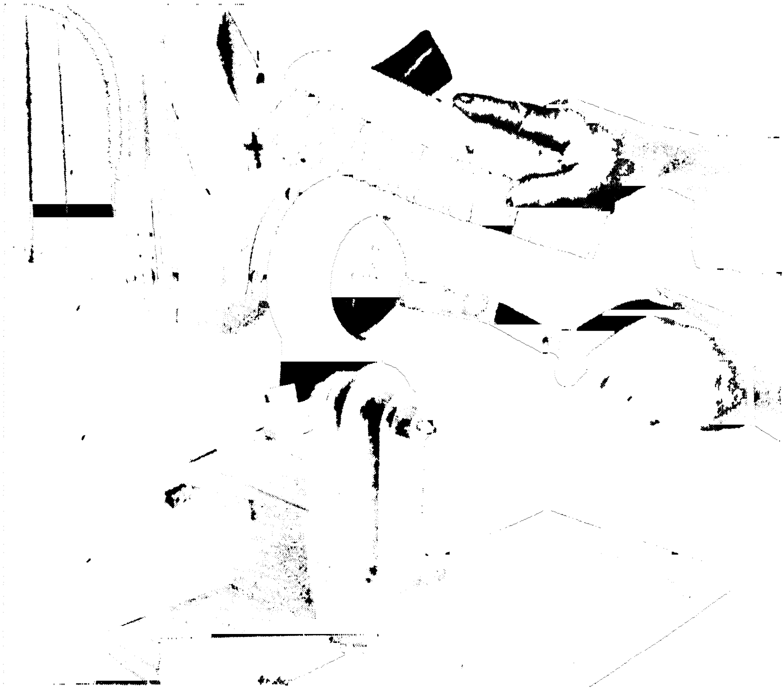


Fig. 1.—VIEW OF SURFACE GRINDER, SHOWING GRINDING WHEEL BEING TURNED BY HAND AGAINST THE ROLLER. THE LIMIT SWITCH SAFETY DEVICE IS ON THE LEFT

cutting clearance. A universal fixture designed to satisfy these requirements is illustrated.

No different grit and grade of grinding wheel, other than that normally used on the work in question, is necessary, and more pieces per dressing can be ground than with a diamond-dressed wheel. The frequency of recrushing will depend upon the type of form to be ground and the accuracy required, sharp edges standing up very well when produced by this process.

As an example, twenty-four form tools of simple form, such as the one shown in Fig. 2 on the magnetic chuck of the machine, have been form-ground with no greater error than ·001 in. before recrushing the grinding wheel. Tools of more intricate form or greater accuracy would necessitate more frequent wheel-crushing. It is desirable that the surface to be ground is cleaned of hardening scale by shot blast or other method.

The crushing roller is machined from tool steel, hardened and ground in the bore and side faces and also on the form. The profile is held to



Fig. 2.—End view of surface grinding machine showing the crushed wheel and the roller together with a sample formed tool

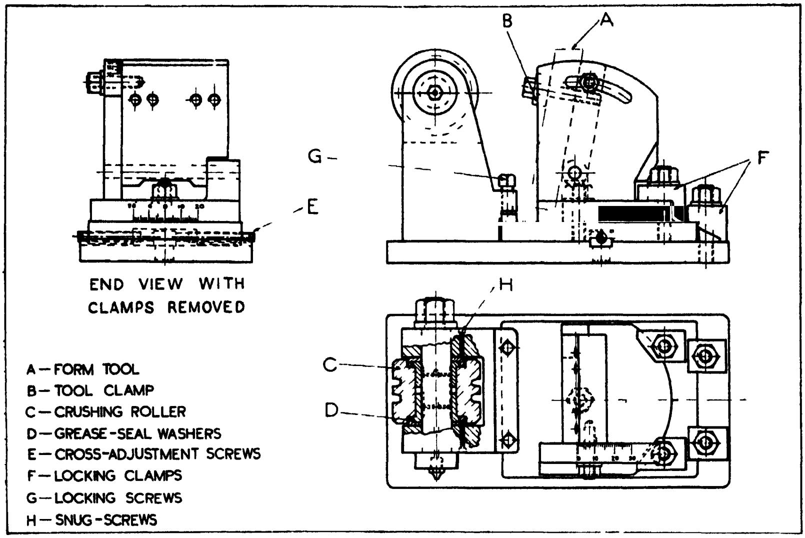


Fig. 3.—DESIGN FOR UNIVERSAL FORM-TOOL HOLDER FOR CRUSHED-WHEEL FORM-GRINDING

form, checked either by means of a profile gauge and light box or by projector on to a large-scale drawing. Flanged phosphor-bronze bushes are fitted and a recessed washer fits over the spindle on each side of the roller and, in conjunction with the bush heads, form a grease seal which excludes the grinding-wheel grit.

The roller must be a close run-fit sideways in order to maintain accurate alignment, and be free on the spindle to ensure that the roller rotates evenly and continuously when in contact with the hand-rotated grinding wheel. It will be apparent that if the roller " seizes," even momentarily, whilst the grinding wheel is being rotated, a flat will be ground on the roller. Concentricity of rollers is also important to avoid excessive stressing of the wheel locally. It is an advantage to flash the roller with hard chrome to prolong its " life " : this can be stripped in the plating shop and replated when necessary.

The spindle on which the crushing roller is mounted is hardened and ground and is provided with a lubricant groove. A very thin grease is injected in ample quantity by means of a gun through a central hole to form not only a lubricant but also a seal at the sides of the roller, as previously mentioned.

The feed of the grinding wheel should not be too heavy. Increments of about ·002 in. for roughing and ·0005 in. when finish crushing, have been found satisfactory.

Chapter XIX

BORING BARS AND FIXTURES

THE process of boring is similar to that of turning, except that because the work being done is internal in character, special bars to hold or carry the tools are required. Although both vertical and horizontal machines especially designed for boring operations are among the standard types of machine tools, as this operation of boring is carried out on the centre lathe, the combination turret lathe and the chucking automatic examples applicable to all these types are included.

Boring Operations

Boring operations may be divided into two classes as follows :

(*a*) Boring bars rotating in the work, as on the usual types of horizontal borer.

(*b*) Work rotating around the boring bar, as on vertical boring machines, lathes, etc.

In each of these the same principles may be applied. The designer should, however, keep clearly in mind which conditions apply when deciding whether the tools should have right- or left-hand cutting edges.

Locating and Clamping

Whilst boring fixtures may embody the details of design previously enumerated, they do not normally require to be as rigidly constructed as, say, the milling fixtures, because the load imposed by the boring tools rarely approaches that introduced by a milling cutter. Nevertheless, similar methods may be used for locating and clamping whilst observing the following additional points.

(1) On rotating fixtures, unless the cutter holders can be made stiff enough, a pilot bush is necessary in the centre of the fixture and in advance of the tools for steadying and centralising the boring bars. Even if piloted boring bars are not used, a central hole is useful for reference purposes. On some machines standard pilot bushes are used which fit into the nose of the machine spindle behind the fixture, which must be provided with a hole through which the boring bar can pass.

(2) On non-rotating or table mounted fixtures, allow ample space between the component and the bushes used for guiding the boring bars so that the tools may be readily inserted.

The spaces should also be adequate to permit unrestricted removal of tools after they have completely passed through the work.

(3) Remember that when the bars are loaded through the component,

the hole or holes in the latter may only be roughly cored, and it is often necessary to make some of the larger tools detachable from the bar on account of this. It is sometimes worth while to clean the bore up to a predetermined size with a smaller bar to ensure sufficient clearance for the regular bar to commence cutting efficiently because of its larger diameter.

So that bars containing fixed tools may be passed through the unmachined bores of the component, the guide bushes can be made in the form of slip bushes. The bar with the tools in position can then be assembled into place by offering it through the work out of centre with the holes to be bored (see Fig. 16).

(4) When facing shoulders inside a component, provide some means for gauging the correct depth of shoulder, either by fitting a gauging collar on the boring bar or by providing suitable gauge blocks on the fixture.

It is proposed, in this section, to show examples of various types of boring bars for both standard and special applications, and then to show fixtures for the various classes of machines, together with several examples showing both fixture and boring bars for a particular operation.

Boring Tools

Cutting tools for use in boring bars are many and varied in type, and the designer will find it necessary to evolve many different patterns for various applications. It is common practice to stock a series of standard boring tools for straightforward work, some arranged for right-hand and some for left-hand cutting. Some firms favour mounting tools at an angle in the bar and others mount them square to the axis, and the design of the tools will depend upon which style is preferred. It is considered that mounting them at right angles or normal to the axis tends towards compactness, but no hard-and-fast rule can be applied for all cases.

Examples of boring tools in common use are shown in Fig. 2. At *A* is seen an ordinary boring tool for right-hand cutting, and *B* is a similar tool designed for left-hand cutting. These tools are suitable for straight-through boring, and may be used for both roughing and finishing, often being mounted in pairs for this purpose.

When it is required to bore up to a shoulder, the tool shown at *E* is used, and is known as a knife tool. These tools are circular in section and are held in the boring bars either by grub-screws, setscrews, taper pins, or wedges. Many methods of retaining and locking tools are in use, and examples of some of these are shown in the boring bars illustrated in this section. The designer should avoid elaborate tool locking arrangements wherever possible, since these may prove unreliable and troublesome when fine swarf is present.

When it is necessary to have a tool overhanging a considerable distance

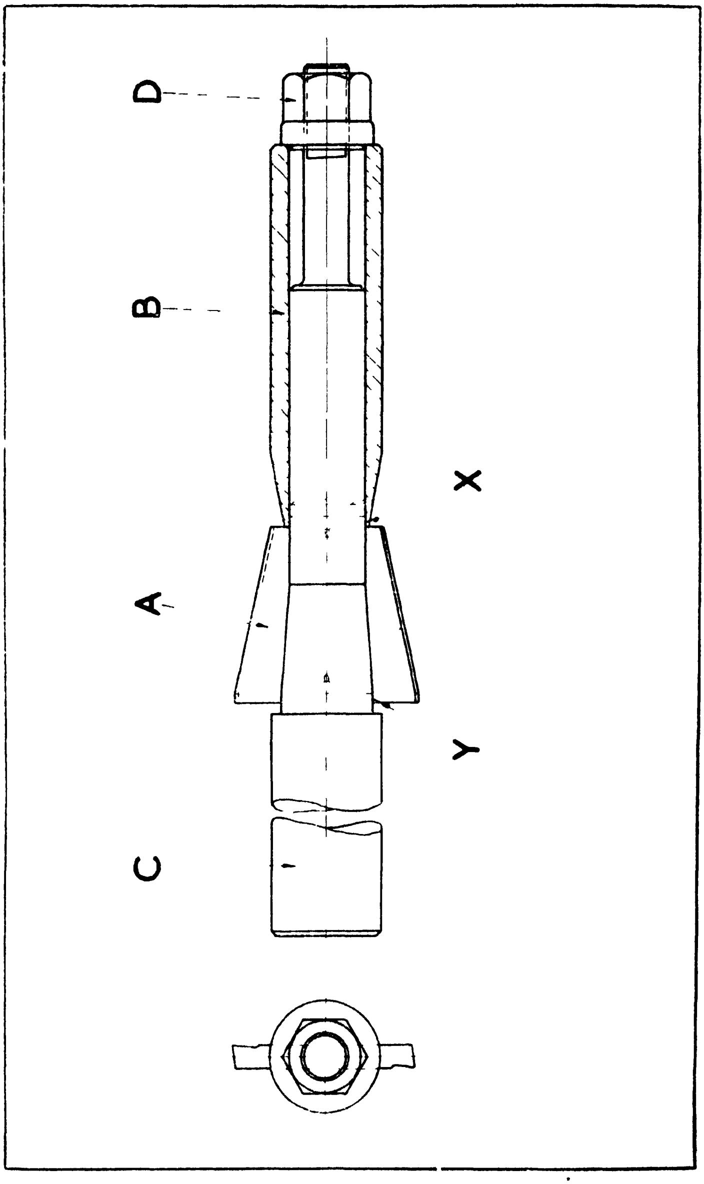


Fig. 1.—BAR FOR FINISH BORING A TAPER

from the bar, the tool should be stiffened up as shown in Fig. 2, *D* and *G*, which are both made for boring and facing large recesses.

Another type of recessing tool is shown at *J* and is provided with two cutting edges. This type of tool is centralised by the slot in its back edge, which engages with two flats ground on the boring bar. Many types of tools are provided for grooving and chamfering, and two examples are shown at *C* and *F*. The grooving tool at *C* is applied to several of the bars which follow. The chamfering tool at *F* is arranged for both right- and left-hand chamfering.

For facing the inside bosses of castings, the cutters shown at *K* and *L* are sometimes used. *K* is a single-sided cutter, and is driven by a pin in the boring bar, which engages in the slot on the back of the cutter. *L* is a double-sided cutter, and is driven by a grub-screw which is tightened on to a flat on the boring bar. These cutters have three teeth on each of their cutting faces. If fractures are to be avoided, sharp corners should never be left in driving slots or for that matter on any part of a cutting tool.

Floating Cutter

At *H* is shown a floating cutter for use when a good finish and accurate size are required. The work must be previously rough and finish bored, leaving about 0·004 in. to be removed by the floating cutter. The cutter is permitted to float in a transverse slot in the boring bar and is centralised by the bore of the component. To enable small adjustments to be made to the diameter of the cutter when worn, the two small grooves shown in the centre are provided. The cutter may be stretched across this neck by using a blunt-ended chisel or by compressing in a vice, the body of the cutter being of soft material for this purpose, and high-speed steel tips being welded on at the ends. The cutter is afterwards reground or stoned to size.

Most boring tools and cutters are made of high-speed steel, although tools tipped with cemented carbide are advantageous where applicable. The cutting angles must be varied to suit the material to be cut, those indicated in the illustrations serving as a guide for general work. It should be remembered that boring tools work inside diameters, and care should be taken to back the tools off sufficiently in order that the back edges clear the radius of the work.

Boring Bars

Boring bars are, as a general rule, satisfactory if made of mild steel, case hardened, and ground. When rough-turning them, however, additional material, approximately ¼ in. over the finished diameter of the bar, should be left adjacent to the tool holes, so that after carburising this surplus material may be removed and the hole or slot then bored or cut.

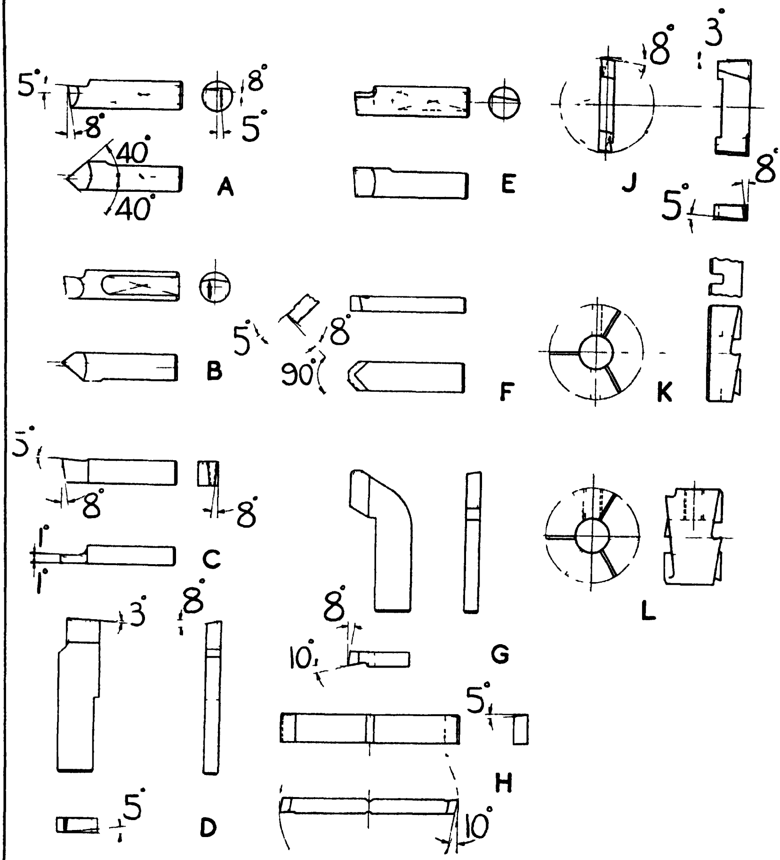


Fig. 2.—BORING TOOLS

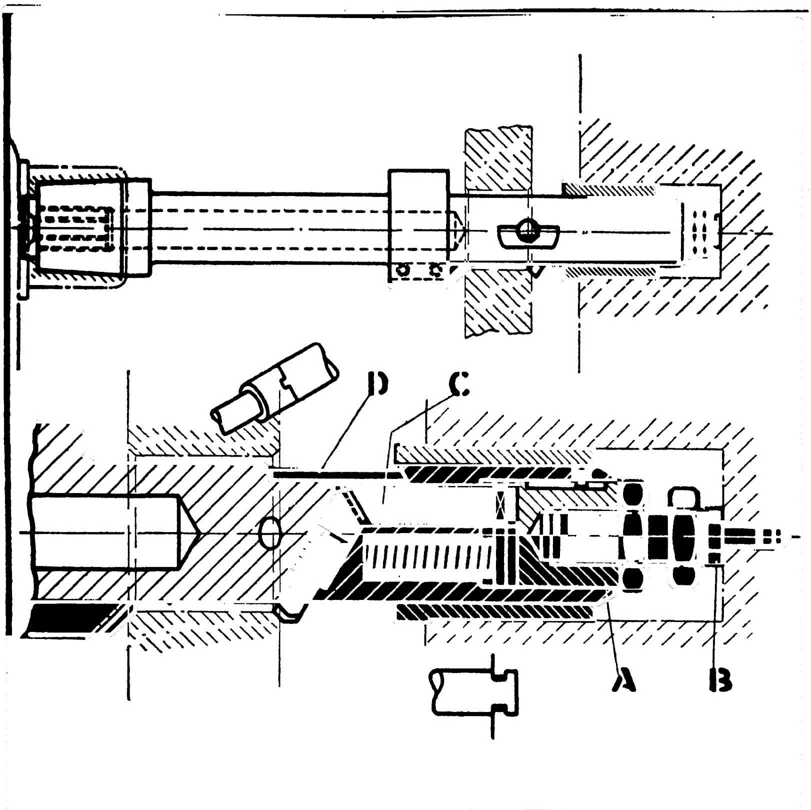


Fig. 3.—Boring bar with back chamfering arrangement

By adopting this method there will be no hardened surfaces at these points. This helps to prevent fracturing, and also permits any slots or holes to be trued up after the dipping off for hardening, during which they are likely to be distorted. Where, however, flats have to be left on the bar for centralising cutters, arrangements should be made so that the carbon can penetrate at such points, leaving hardened locating positions which can subsequently be ground accurate and central for the tools. Bars should be made long enough to ensure that they are properly piloted in either the fixture and/or the machine before cutting commences and that they remain piloted until cutting is completed. Furthermore, the traverse on the machine should be checked to ensure that this

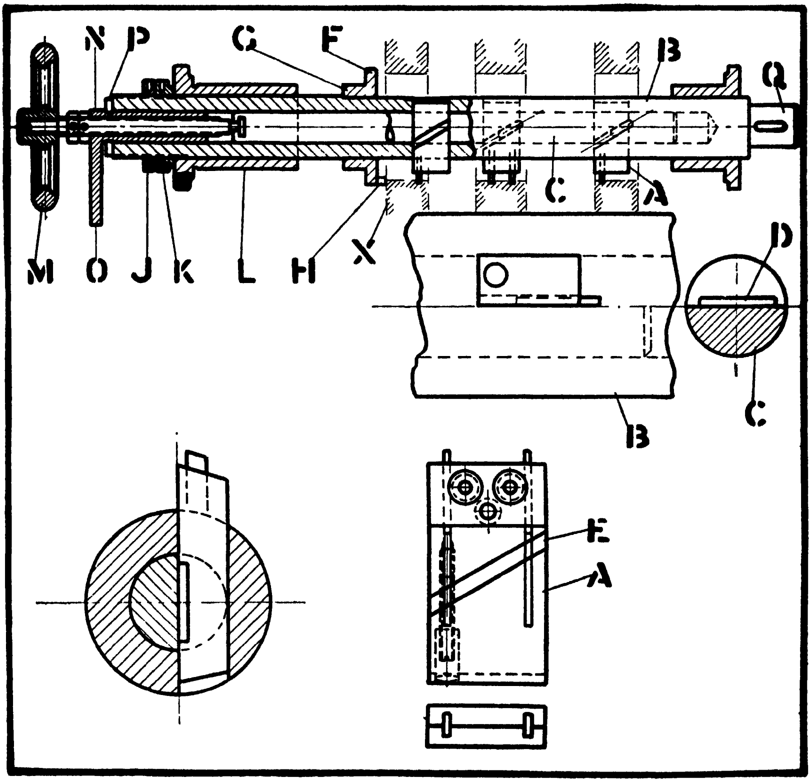


Fig. 4.—RECESSING BAR

is sufficient to allow the proposed bars to enter the fixture with the work in position.

The bar shown in Fig. 1 is for use on a turret lathe and holds a flat cutter *A* for finishing a taper bore. It is essential that this cutter is held central at both ends, and the front or piloting portion of the bar is made in the form of a sleeve *B* for this purpose. The front of the cutter is provided with a spigot *X*, which fits inside the sleeve *B*, and the rear end of the cutter has a recess *Y*, which locates over two flats ground on the bar *C*. The sleeve is also used to clamp the cutter in position by tightening the nut *D*.

Back Chamfering Bar

The type of boring bar shown in Fig. 3 is very useful for preventing a second operation (particularly on automatic chucking machines). The

boss shown being machined is part of a stamping, the operation in this case being to bore and chamfer both sides of the boss, the two faces having been previously milled.

A component is set up one on each of the four faces on the turret of a chucking automatic, and the boring bar is held in the spindle. It will be noticed that this is the reverse of the usual practice, but by this method loading time is eliminated, because work pieces can be loaded and unloaded from one face of the turret whilst boring is taking place on another. It is necessary, therefore, to avoid a second operation, that a component be finished complete on each turret face.

Because the bar does not travel but merely revolves, the only movement available for operating the back chamfering tool is the forward and return motion of the turret. The tool producing this chamfer has to finish cutting at the same time as the front tool, exactly at the end of the forward motion on the turret. The machine then trips into fast return whilst these two tools are at the finish of their cut. In order, therefore, to get the back chamfering tool away from the work, it is necessary for it to return into the bar at a faster rate than the face it has finished chamfering moves towards it. The tool cannot move back before the turret commences moving, because there is no motion available to make it do so.

It is arranged that the back of the tool acts as a cam and the tool is set at 60° ; as the chamfer being machined is 45°, the difference in relative speed prevents the component fouling the tool. To operate this tool a plug *A* is fitted into the end of the bar, into which an adjustable screw is fitted. This adjustable screw meets a hardened pad *B* in the bore of the turret, and consequently pushes the sliding piece *C*, coupled to the tool, which in its turn pushes the tool forward.

The plate shown on top of the bar at *D* acts as a cover for the previously bored tool hole and as a retaining plate for the sliding member. The springs fitted beneath the shoulder on the tool and in front of the end plug *A* operate simultaneously for returning the tool into the bar.

Recessing Boring Bar

There are four recesses in the bore of the component shown partly in Fig. 4 which have to be machined to very close limits, not only with regard to their relative distance one with another, but also from the finished face of the component at *X*. The diameters also of the recesses have to be very accurate. The arrangement shown has satisfactorily simplified what would otherwise be a difficult and costly operation.

The strip tools for forming the recesses are held in holders shown at *A*, which are a good sliding fit in a slot cut in the tube *B*. The bar *C* is D shaped, and across the face the keys *D* are left standing, which fit into keyways *E* in the tool blocks.

To keep the tools in the correct relative position to the machined face

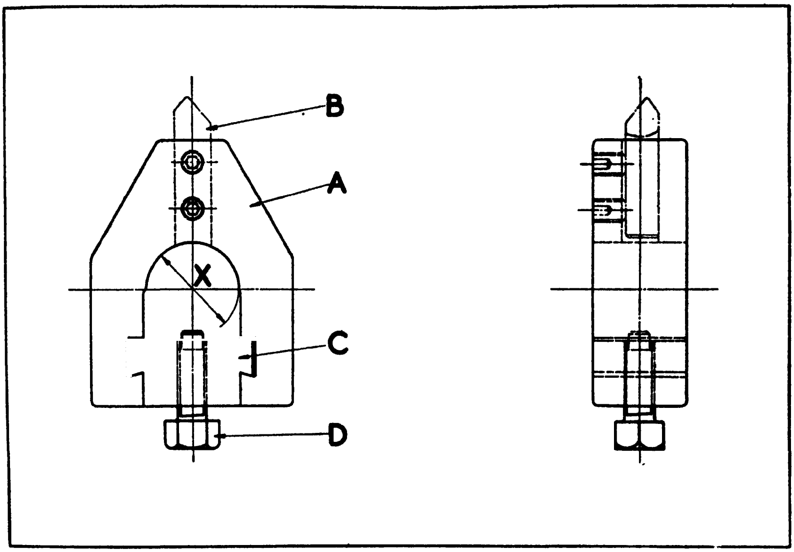


Fig. 5.—Detachable boring head

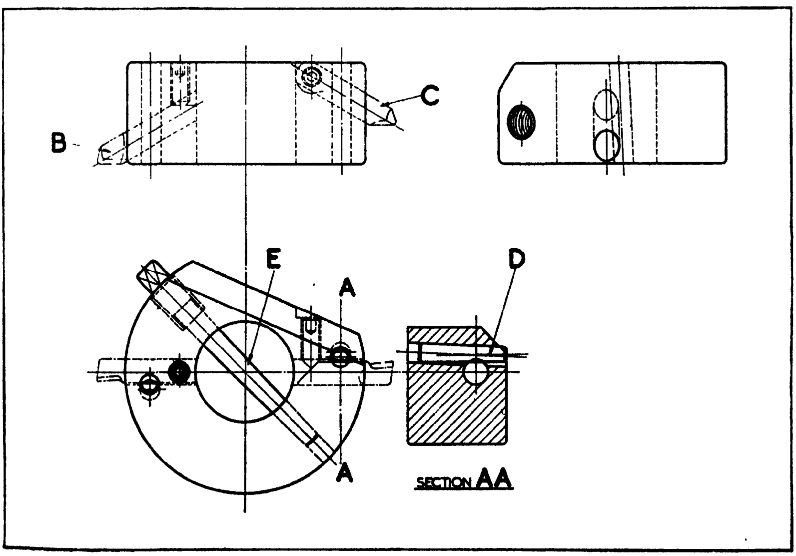


Fig. 6.—Boring head for roughing and finishing

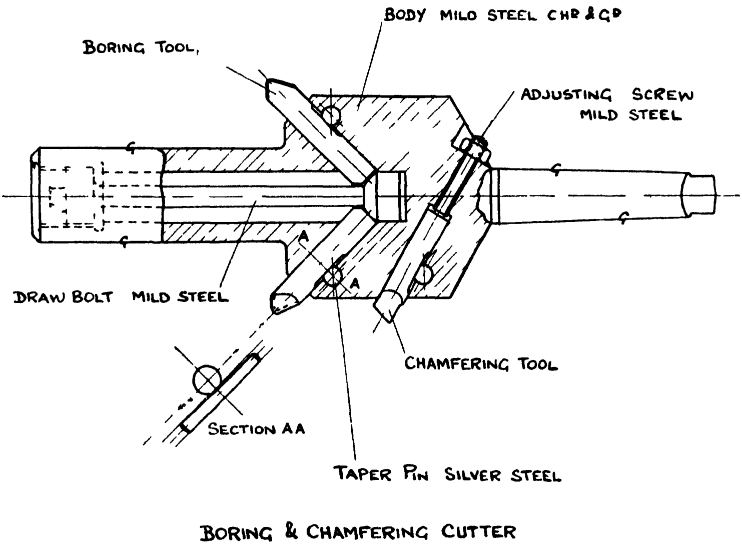


Fig. 7.—HEAD FOR BORING AND CHAMFERING

of the component, the U-shaped slip collar at *F* is dropped over the bar against the shoulder at *G* and a bar gauge *H* inserted between the face of the collar and the work. From this setting the locknuts *J* and *K* are adjusted against the bush *L* in the boring jig.

The bar operating the tool blocks is fed by the hand-wheel and screw *M* operating in the nut *N*, which cannot revolve, it being anchored to the jig by the arm *O*. The depth of the grooves is controlled by previously setting the locknuts *J* and *K*, which limit the travel of the screw.

The end of the nut *P* in the bore of the bar prevents the key from being wound past the end of the slot in the tool block, thus allowing the tools to fall out of the bar, the nut itself being anchored by a split washer

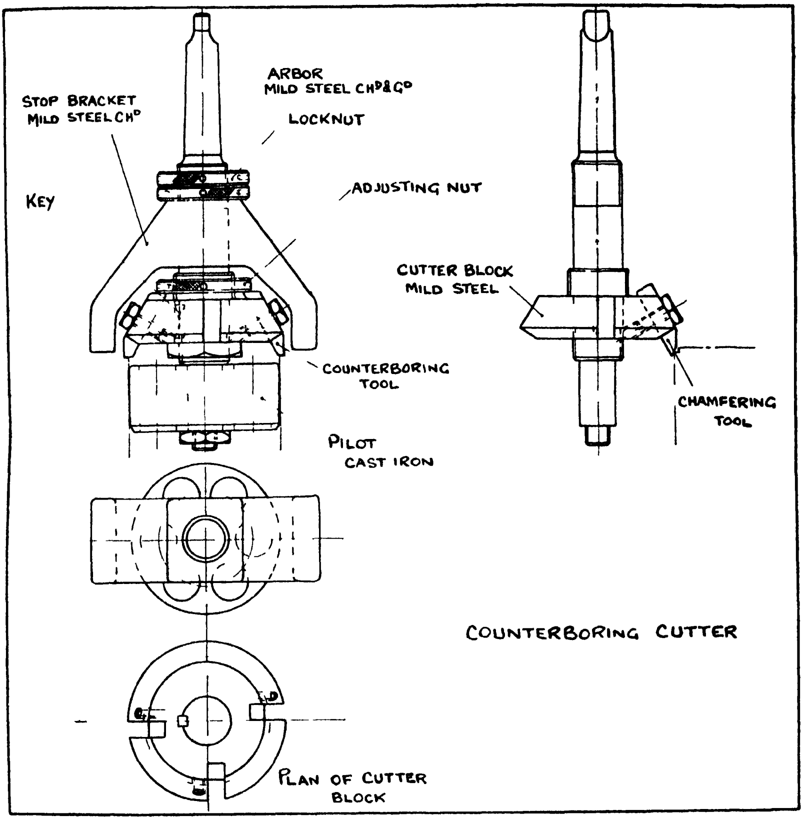


Fig. 8.—HEAD FOR COUNTERBORING AND CHAMFERING

in a groove against the arm. The bar is attached to the machine spindle and driven by the end *Q*.

Boring Heads

It is sometimes desirable, when boring large diameters inside a component, to provide one or more loose boring heads which can be attached to the boring bar and so prevent the excessive overhang of the tools which would otherwise occur. A simple example of such a head is shown in Fig. 5 and consists of a steel block *A* which carries a boring tool *B*. The block is bored to a diameter *X* to fit the bar and slotted out on one side to take the retaining block *C*, which is loosely dovetailed into it.

The head is held to the bar by tightening the bolt *D*, and may thus be placed in position without removing the bar from the fixture and also clamped in any position along the bar.

A head for a similar purpose is shown in Fig. 6. Two tools are fitted, one for roughing, *B*, and the other for finishing, *C*, and are held by wedge pins *D*. These latter are parallel pins with a flat ground along their length at an angle of approximately 2½° to the axis. The head is held to the bar by a taper pin *E*, which passes through it and the head. The taper pin has a threaded portion on its end which fits a tapped hole in the head to facilitate withdrawal, the pin being turned by means of a square milled on the end of the thread.

A head for boring and chamfering is shown in Fig. 7. It carries two boring tools, which are adjusted uniformly by the drawbolt running through the pilot. After adjustment, the tools are locked by wedge-pins. This head is used on a drilling machine, and the pilot on the front end fits a previously drilled hole in the component.

Another head for use on a drilling machine is shown in Fig. 8. This is for machining a counterbore and chamfering the bore in a previously bored hole. Two tools are provided for counterboring, and are adjusted uniformly by a nut. A separate tool is fitted at right angles to these for chamfering. A large pilot is fitted to suit the bore of the component, and the pilot is made a run fit on the end of the boring bar. To control the depth of the counterbore, a stop bracket is provided, and is adjusted by two locknuts. The bar is fed downwards until the stop bracket rests on the top face of the component.

The head shown in Fig. 9 is for use on a horizontal boring machine. The shank *A* is screwed to the machine nose and runs in guide bushes in the boring fixture. The actual boring head *B* is made detachable from the shank to enable heads for various sizes of bore to be fitted, and thus permits several different components to be machined in the same fixture. The head carries four tools, and the machining of the recess is completed in one operation.

The four tools are as follows :

C : Tool for counterboring the bottom of the recess.

D : Tool for facing the bottom of the recess.

E : Tool for boring the register.

F : Tool for facing the top of the recess.

The head is centralised in the shank by the taper shank adjacent to the thread.

Setting Gauges

Consideration should always be given to the question of providing the operator with gauges for setting the tools in a boring bar, particularly where the tools are normal to the axis of the bar and it is not possible to check over the point of the tool with a micrometer. Such gauges are

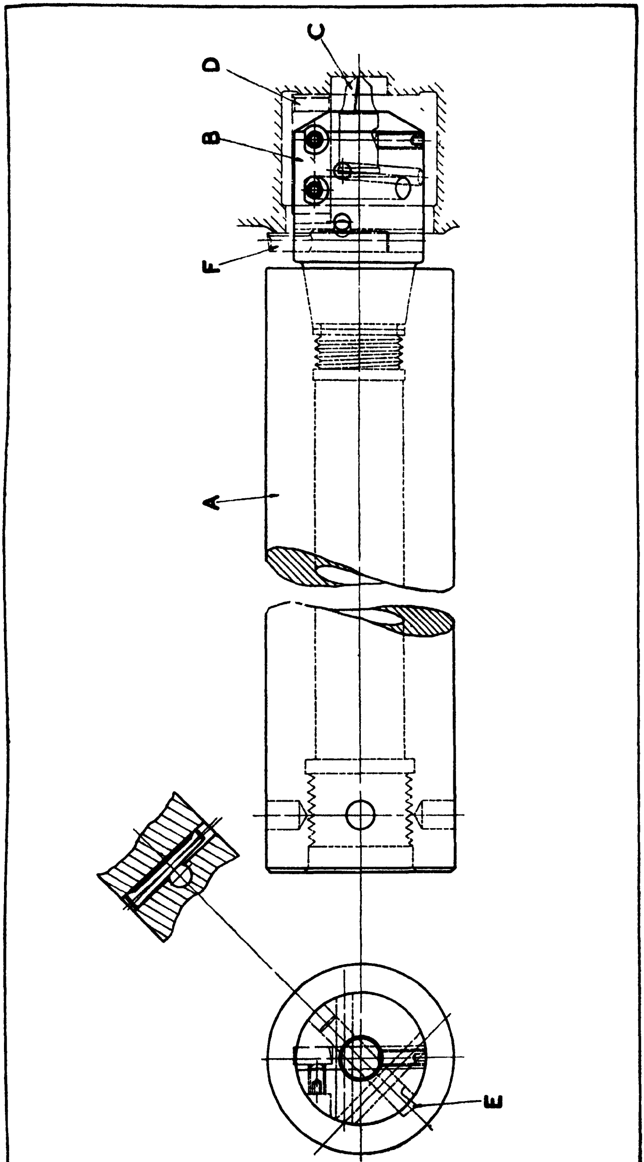


Fig. 9.—Boring bar using interchangeable heads

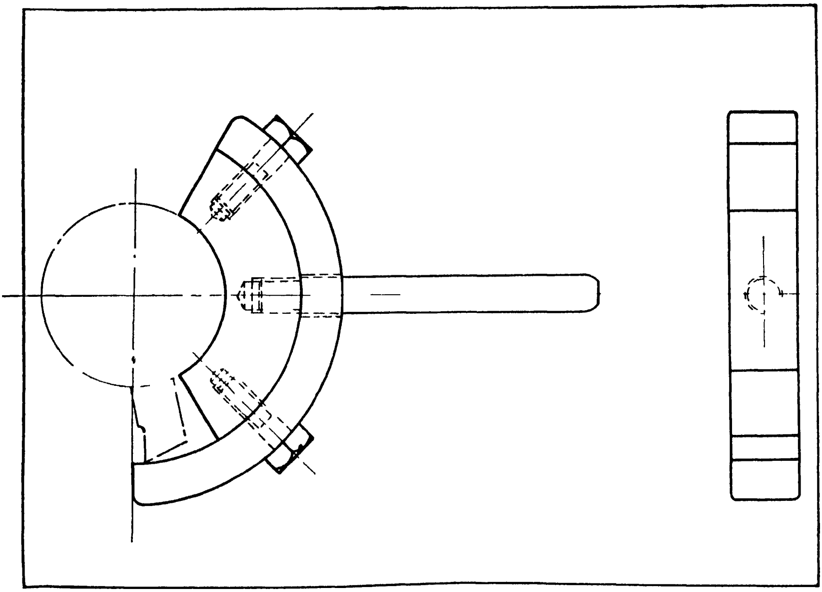


Fig. 10.—Setting gauge for boring tool

mostly of a type which is ground to seat on the diameter of the boring bar and provides a step or steps against which the tool may be adjusted. One of these gauges is shown in Fig. 10. It is built up from two pieces to provide a tongue the correct radius for setting the tool. A handle is fitted to assist the operator to use the gauge inside the component. Another setting gauge is shown in Fig. 11 and is made from mild steel, case hardened and ground. This gauge provides two steps, one of which is equivalent to the finished bore of the component and is used for setting the finishing tool, and the other is made to a smaller radius and is used for setting the roughing tool.

Boring Fixture for Vertical Machine

The fixture illustrated in Fig. 12 is designed for use on a vertical boring machine, which is, in effect, a vertical turret lathe. The operation in question is that of boring the large bore in the centre of the casting. Previous machining has consisted of milling the large boss on each side of this bore and milling the feet. The component is located by these feet against two wear strips *A*, and is held in position by the handscrew *B*. Location in the other direction is provided by two further handscrews *C* 1 and *C* 2, which are adjusted to bring the main bore central in order

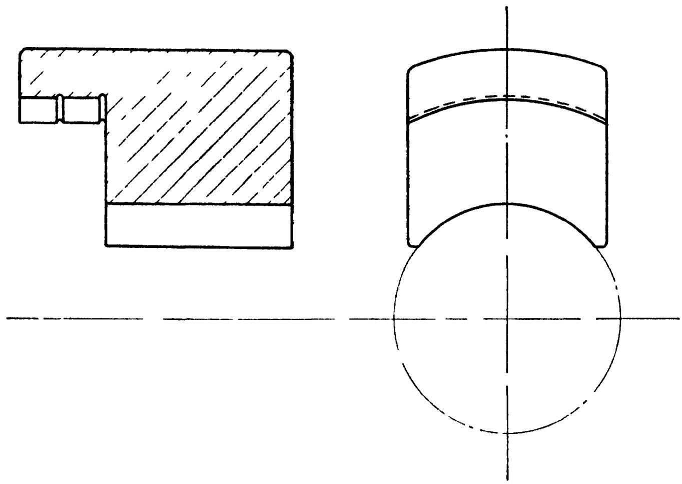


Fig. 11.—Setting gauge for boring cutters

that an equal amount of metal is machined from each side. The component is clamped to the fixture, and rests on one of the machine bosses by the three clamps *D*.

In order to centralise the fixture on the machine table, a spigot is fitted which fits loosely into a recess in the table, and the fixture is finally trued up by the groove *F*, which is true with the locating faces. A balance weight *G* is cast on the fixture, and is adjusted to give correct balance on completion of the fixture.

Boring Fixtures for Turret Lathes

In Fig. 13 is shown a useful though simple arrangement for boring two holes in line when the back bore is larger than the one at the mouth of the component and there is no gap in the casting through which the tool cutting the larger diameter can be set in position.

The end of the bar attached to the turret is therefore hinged to allow the bar to drop, when being passed through the component, as much as the cored hole will permit, allowing the leading tool for the large bore to pass through the smaller cored hole. The amount of drop is also controlled by a flat on the bar at *A*. When the tapered end of the bar positions itself into the bell-mouthed pilot bush, both tools are brought

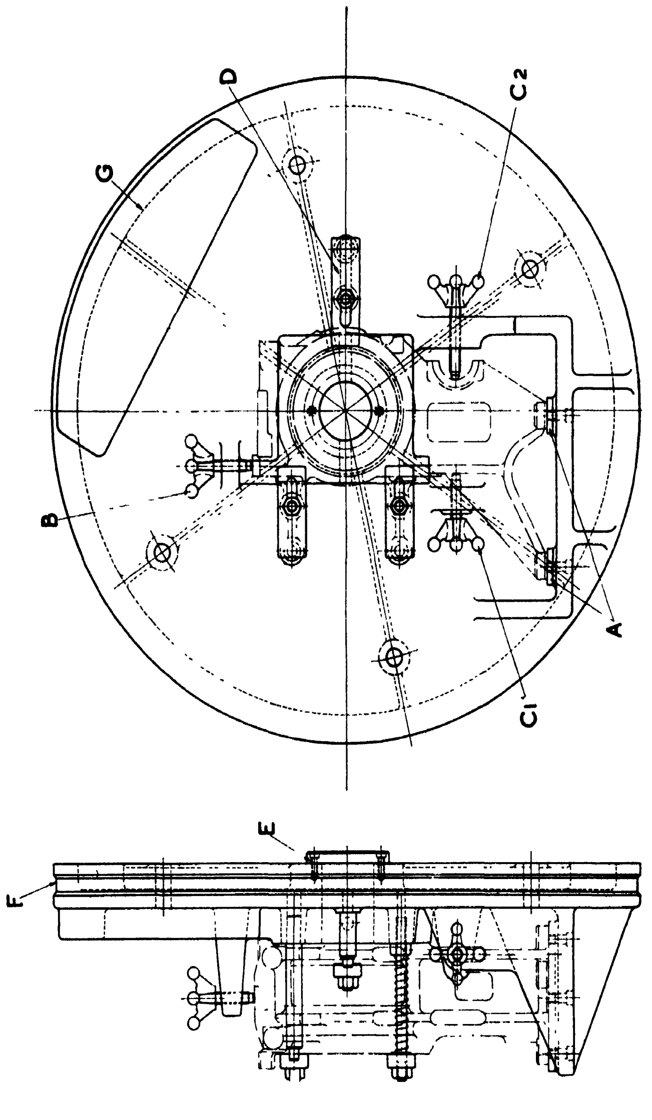


Fig. 12.—Fixture for a Vertical Borer

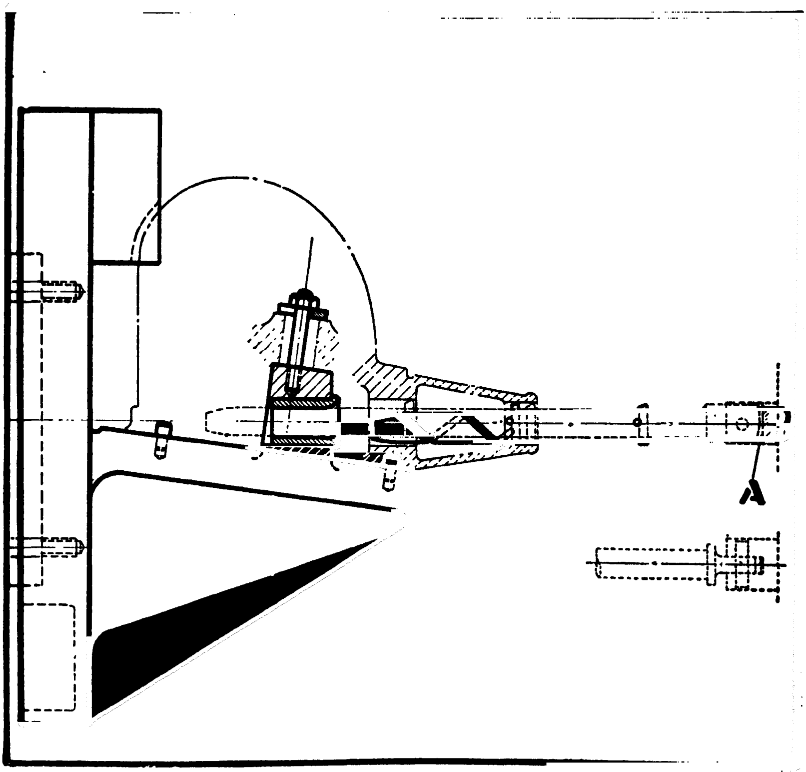


Fig. 13.—BORING FIXTURE FOR USE IN TURRET LATHE

into correct boring position and remain permanently set for size. Roughing and finishing bars are used and remain permanently fixed in the turret.

Tooling equipment for a boring operation on a turret lathe is seen in Fig. 14. The equipment consists of a fixture, steady, and two bars fitted with the necessary tools. The operation is that of rough-and-finish boring the hole through the shank of the component, including the taper and reduced diameter at the inner end. To assist in holding the component, two collars are turned previously on the outside diameter, one to locate in the fixture and the other to run in the steady. The fixture consists of a cast-iron cradle *A*, which is recessed and provided with studs at the back and is located on and bolted to the adapter plate of the

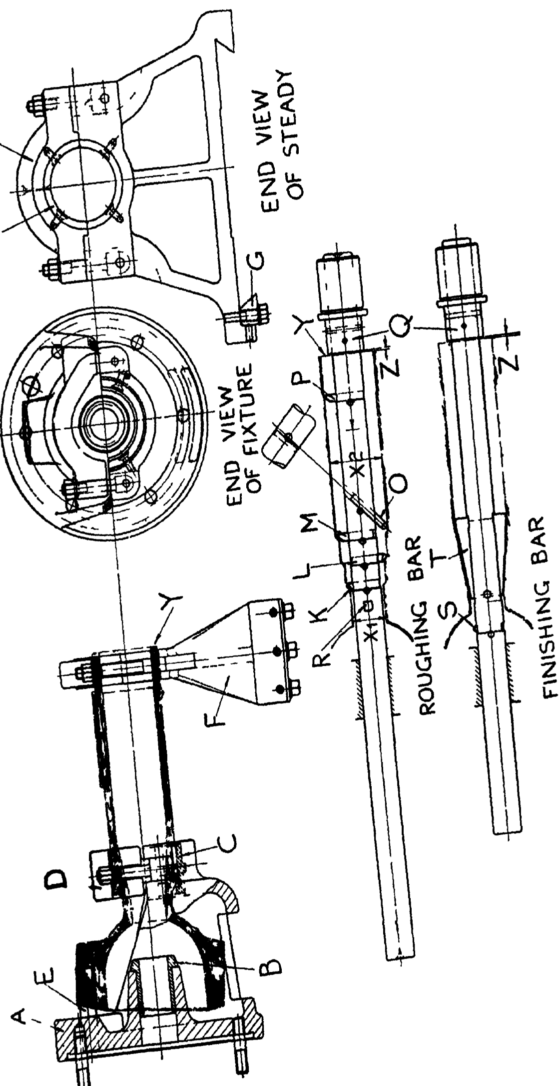


Fig. 14.—Boring equipment for a turret lathe

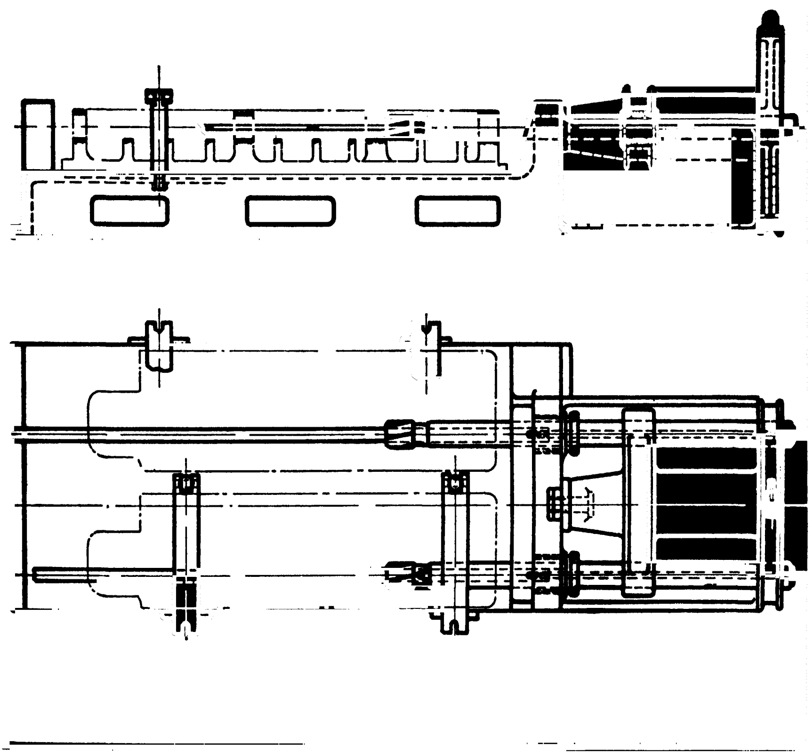


Fig. 15.—Boring fixture for long interrupted bore

machine. A pilot bush *B* is fitted in the centre of the fixture, and is of a diameter to suit the two boring bars. The component is located in a half bush *C*, which is screwed to the fixture and is tongued thereto to resist the axial pressure of the cut. Axial location is provided by pushing a shoulder on the component against the rim turned on the half bush. The component is retained in position by a strap *D*, which is tightened by a swing bolt. A driving pin *E* is fitted which drives on a boss on the component.

The steady bracket *F* is machined to fit the bed of the machine, and is clamped in position by a gib *G*. A loose top cap *H* is fitted, which is located by a register as shown and held by two swing bolts. The com-

ponent runs in a split phosphor-bronze bush *J*, which is provided with means for lubrication.

Before this boring operation, the shank of the component is rough drilled right through to a diameter X^1. The end face *Y* is also machined to give a gauging face for measuring the penetration of the boring bars and to locate the taper in its correct position in the bore. The three tools *K*, *L*, and *M* in the roughing bar serve to remove the bulk of the surplus metal from the bore and, when fed in to depth, leave the taper in the form of steps ready for finishing. The tool *O* acts as a finishing tool for diameter X^2, and leaves 0·004 in. in this bore for finally floating to size to obtain a tolerance of 0·002 in. A clearance diameter at the front end of the bore is provided by the tool *P*. A collar *Q* is provided on both bars, and they are fed into the work until dimension *Z* is obtained between the collar and the end of the work. This dimension is checked by a slip gauge, and indicates that the correct depth of boring has been reached. After the roughing bar has been fed into the work, it is withdrawn, and a floating cutter is fitted in the square hole *R* for finishing the diameter X^2. The floating cutter is fed into the work until the line marked on the bar with the arrow adjacent coincides with the end of the work.

After floating the large bore, the turret is indexed to bring the finishing bar into position. This bar carries a tool *S* for finishing diameter X^1 to size, and also a flat cutter *T* for finishing the taper and blending a radius at each end.

Fixtures for Horizontal Boring Machines

This fixture, shown in Fig. 15, is for a long bore in a component, the bore being approximately 3 ft. 6 in. long and 2¼ in. diameter.

It will be noticed that, in addition to the main bores which have to be machined, there are a number of webs, in this instance used as oil weirs, which must also be machined. The result is that there is no space available to arrange steadies on the bar in conformity with normal practice.

It is therefore arranged that the boring bars pull four fluted roughing and finishing tools throughout the length of the hole, and also, close behind the tools, a quill which friction prevents from rotating, and is a good fit in the hole being bored. This quill follows along behind the tool for the whole of the length of the operation. The roughing and finishing is done simultaneously on two components placed side by side, one being roughed and the other finished.

The end of the jig is provided with a rotating member carrying the quills, which vary in diameter to suit the roughed and finished bores. At each traverse of the machine a finished component is exchanged for an unbored one, and the quills withdrawn off the bars.

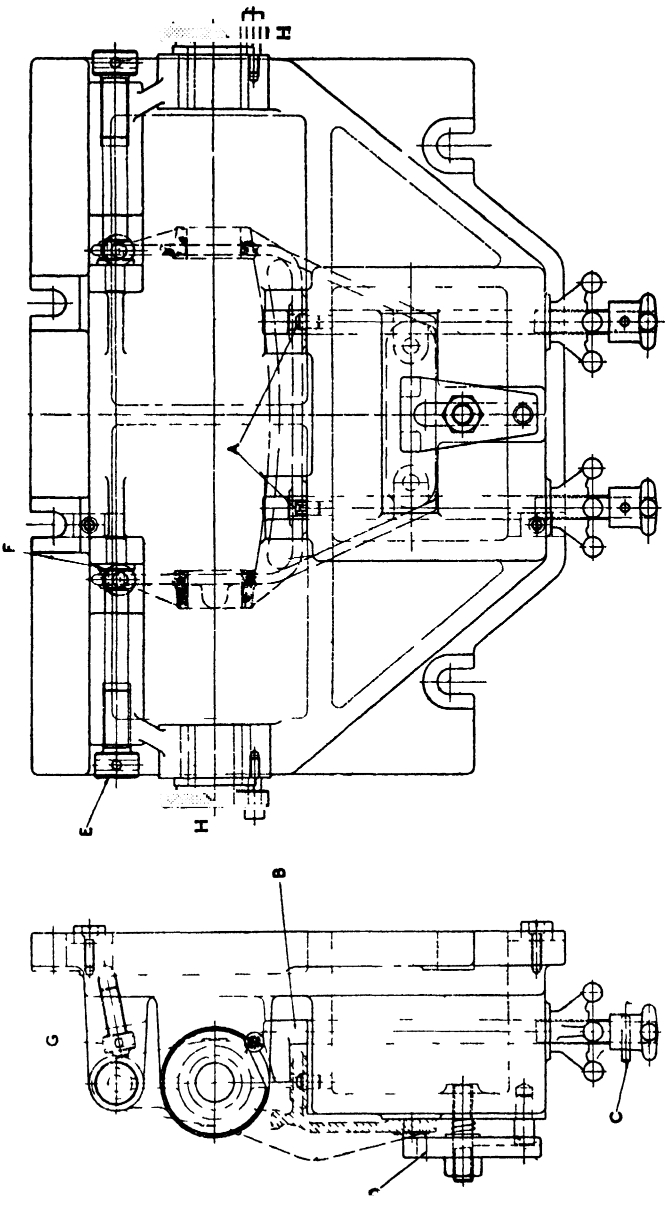


Fig. 16.—Boring and Facing Fixture for Use on Horizontal Machine

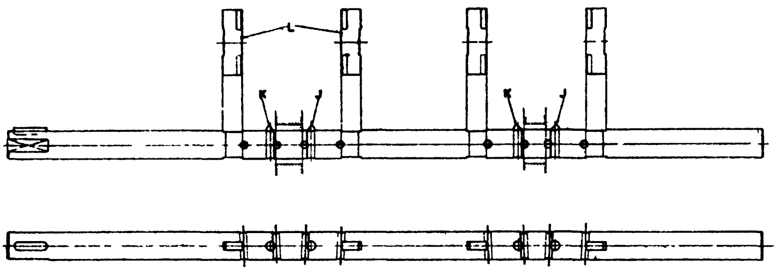


Fig. 17.—Boring and facing bar for use with fixture shown in fig. 16

This allows the cutters to be changed over, the quills indexed half a turn and coupled up to follow their respective bars.

For removing the boring bars when putting on a fresh component, the rotating member is turned until cored holes are opposite the bars, which can then be dismantled.

Boring and Facing Fixture for Use on Horizontal Machine

Fig. 16 shows another fixture for use on a horizontal borer, and the bar for use with this fixture is shown in Fig. 17. The operation is that of rough and finish boring and facing both sides of two bosses. The component is of a rather frail nature, and for this reason is well supported during the boring operation.

Location is taken from two faces which have been previously milled, and two locating pins *A* are used which fit into drilled holes in one of the faces. The component is held on to the locating pins by two long hook bolts *B*, which are locked by hand. The pins *C*, which hold the knobs on to the hook bolts, are left projecting on one side to provide an indication as to when the head of the hook bolt is in its correct position. When the hook bolts have been tightened, clamp *D* is brought into position and tightened. To support the projecting ends of the lugs being bored, two jack screws *E* are fitted which clamp the bosses on the lugs against hardened buttons *F*. Two small support screws *G* are provided to assist in locating the component. It should be noted that ample space

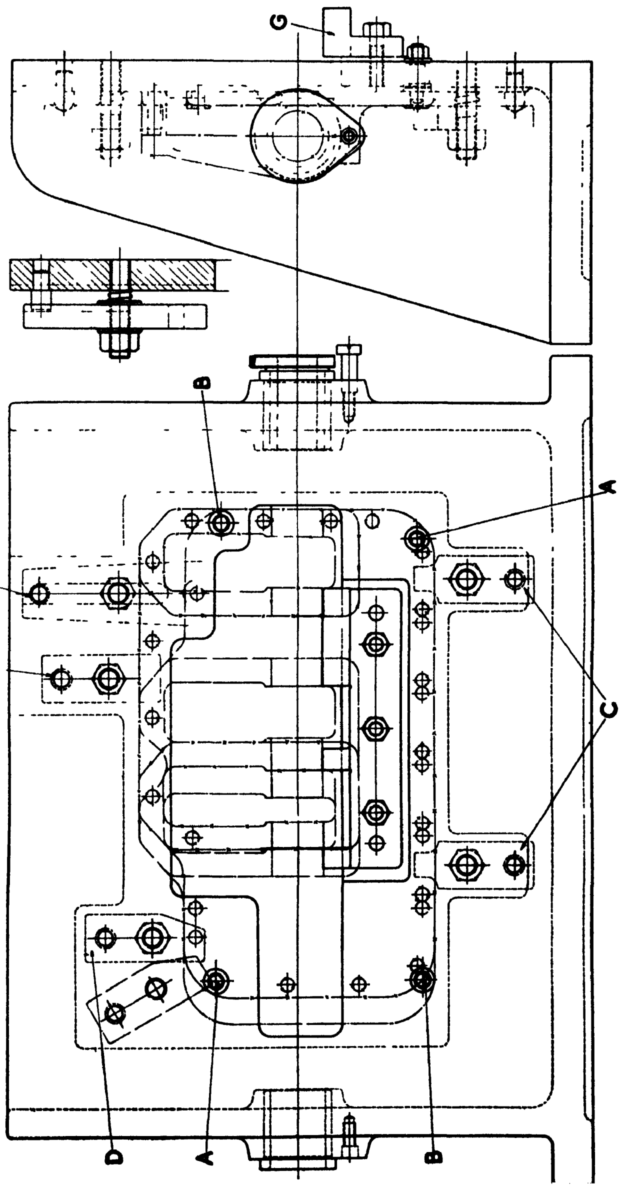


Fig. 18.—Fixture adaptable for two components on a horizontal borer
One component shown . . . . : and the other — x — x.

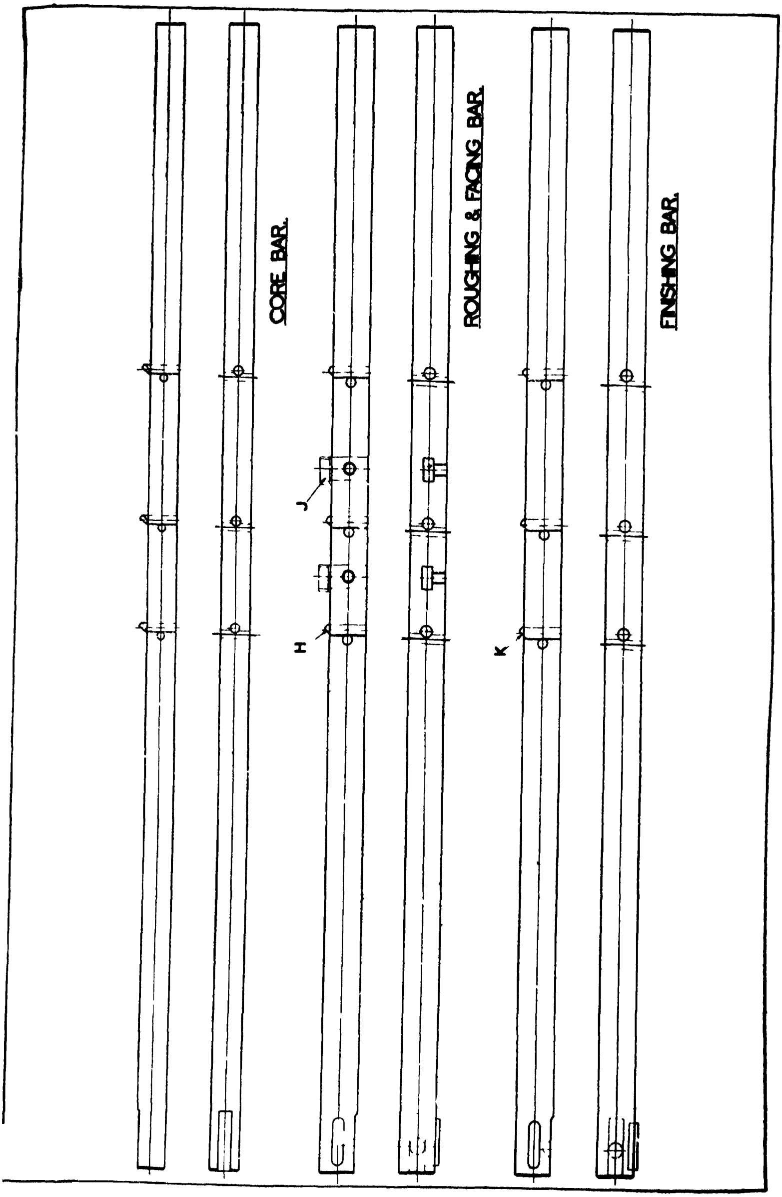


Fig. 19.—SET OF BORING BARS FOR USE WITH HORIZONTAL BORING FIXTURE IN FIG. 18

is left between the slip bushes *H* and the bosses of the component to allow for inserting and removing the facing cutters. The boring bar has two roughing cutters *J*, which are fed through the work, and the feed is then reversed to allow the finishing cutters *K* to pass through. Four facing cutters *L* are provided, two having right-hand and two left-hand cutting. These cutters are centralised in the bar by the slots cut in their back faces.

Boring Through Five Bosses on a Cover

The fixture illustrated in Fig. 18 is for boring through five bosses on a cover with a cap in position and is adaptable for two sizes of component. The bars for use with this fixture are shown in Fig. 19. The fixture consists of an angle bracket, with two movable locating pins *A*, which are placed in alternative positions *B* to suit the other components. The two clamps *C* at the bottom are suitable for both components, clamp *D* is placed in one or the other of two positions, and clamps *E* and *F* are alternatives, one or the other being used, depending on which component is being machined. As it is necessary that the various bosses on the component are spaced accurately in relation to one another, the gauge block *G* is provided for setting the tools when facing the bosses, and the position of the facing tools is set with a straightedge.

Separate Bars for Roughing and Finishing

The first boring operation consists of using the core bar to clean up the cored hole in the component and to ensure that the larger bars used for boring and facing may be passed through. The roughing and facing bar carries three rough boring tools *H* and two facing cutters *J*. The finishing bar carries three finishing tools *K*. By providing separate bars for roughing and finishing, it is possible to leave the tools set to the correct diameters for both components, whereas if the roughing and finishing tools were in the same bar, it would be necessary to remove some of the tools to prevent them fouling on the component.

A Hint when Designing Bars for Boring Components

It is recommended that, when designing bars for boring components such as this one in which there are several tools cutting at the same time, the draughtsman should lay the bars out on a separate piece of transparent paper. This enables the bars to be laid on the fixture drawing and moved backwards and forwards as they move when cutting, and will ensure that the tools do not foul the component in any of their working positions and that they also clear the fixture, steadies, etc.

Fixture for Production Boring Machine

Fig. 20 shows a fixture for boring a gear casing on a production boring machine and Fig. 21 shows the set of three bars for the operation. The component is located by two pins *A* in the base, and is held thereto by

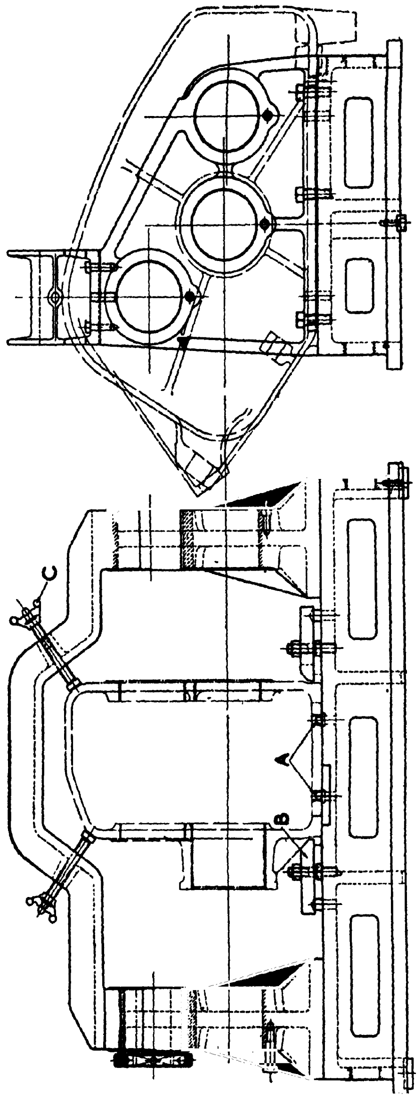


Fig. 20.—Fixture for use on Production Boring Machine

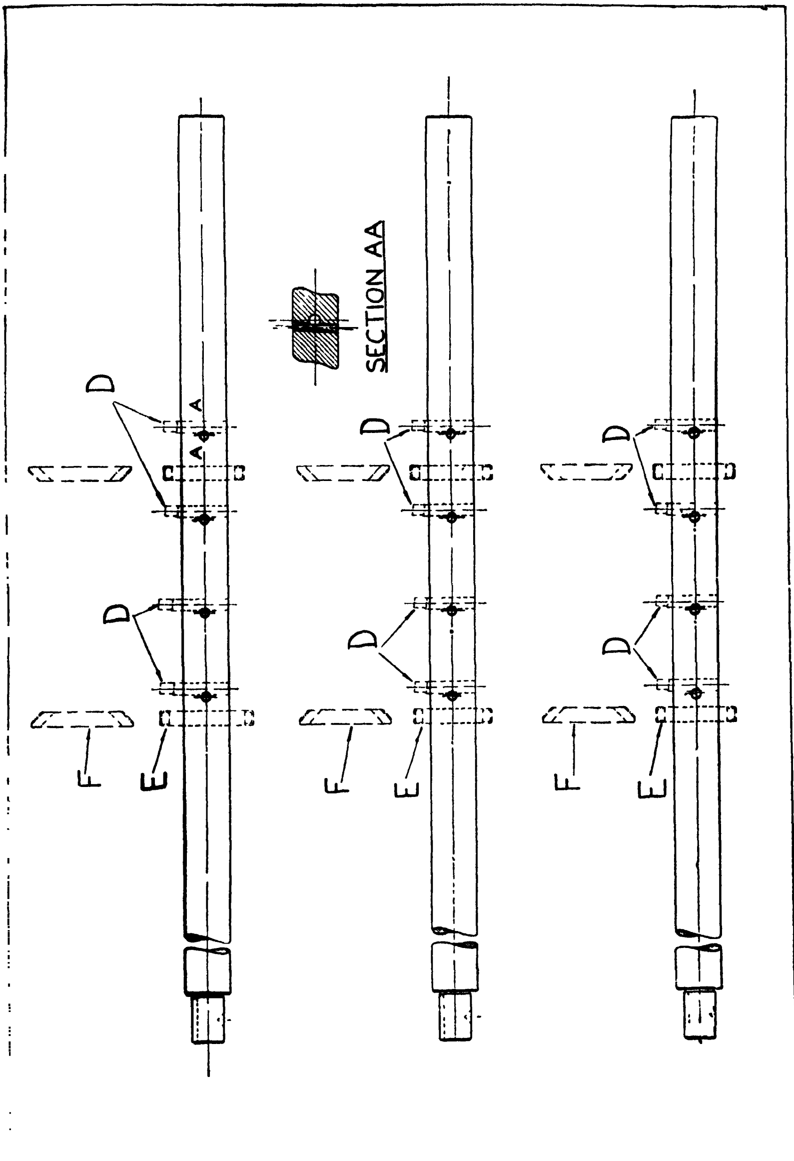


Fig. 21.—Set of Boring Bars for a Production Boring Machine

two clamps *B*. Two steady screws *C* are fitted to the bridge piece of the fixture and are tightened by hand. The three bars each run in slip bushes at either end, and, to prevent mistakes when assembling the bars to the fixture, the diameters of the three bars are varied slightly, there being 2 mm. difference between the smallest and largest.

The bars are fitted with roughing and finishing tools *D*, and in addition interchangeable floating cutters *E* and chamfering tools *F* are provided as shown.

This fixture is used with the multi-spindle head shown in Fig. 5 in the section on Multi-spindle Heads.

Chapter XX

AIR-OPERATED FIXTURES

COMPRESSED air as a source of power for the manipulation of jigs and fixtures is of primary importance, and it can, when quantities warrant the expenditure involved, be readily adopted for clamping, locating, and even ejecting the work from the fixture. Not only may manual effort be reduced to the mere movement of a valve lever, but the general handling time is reduced to a minimum.

Many machine tools are fitted with pneumatic chucks. Such chucks are, of necessity, of the self-centring type and are made with two, three, or four jaws. The jaws may be either solid or detachable, as on ordinary self-centring chucks, the latter being more useful and permitting the chuck to be equipped with sets of interchangeable jaws for various components.

Two main types of standard chucks are available ; in one the jaws are operated by bell-crank levers, and in the other a wedge mechanism is used. In either type the power is applied through a pull rod which is coupled up to an air cylinder. Standard chucks are illustrated both photographically and diagrammatically in the makers' catalogues.

This section is intended to describe, therefore, the application of compressed air in fixture design and its use for solving awkward tooling problems. Air cylinders may be bought as units ready for building into machines or fixtures and, for this purpose, are provided with various forms of mounting. Lugs or flanges are cast on where convenient, or the cylinder may be hinged and thus becomes one member of a link motion. Rotating cylinders are also obtainable for mounting on machine spindles and are provided with rotary glands for supplying the air to operate them. When an organisation is using a number of air cylinders it may be found more convenient to keep in stock the various parts and to build the cylinders up integral with the fixtures or machines, this method often proving more compact where space is limited.

A complete pneumatic equipment should include, in addition to the air cylinder or cylinders, the following items :

(1) Stop valve for isolating the equipment.

(2) Reducing valve, by means of which the pressure on the work may be regulated instantaneously from the maximum down to a few pounds per square inch, or to that pressure found most convenient to avoid distorting the work.

(3) Dial pressure gauge graduated in pounds per square inch in the cylinder.

(4) Lubricator, by which oil may be blown into the cylinder.

Items (2) and (4) are sometimes dispensed with, as it is not always necessary to vary the pressure on the work, and normal methods of lubrication may be employed.

In addition to the above a control valve is required in a position handy for the operator. This valve may be either hand or foot operated, to suit the application in question, and many useful types are on the market.

Whatever air pressure is in use on a factory system, it is advisable to allow for a drop in pressure between the compressors and cylinders of approximately 10 per cent., to allow for the length of the air lines. On most installations a pressure of about 80 lb. per square inch is maintained in the cylinders, and this figure may be used as a basis for calculations. Instances are on record where this figure is reduced to 6 lb. per square inch for finishing operations on fragile cast-iron work.

Two constructions for built-up air cylinders are shown in Figs. 1 and 2, the differences in the two being in the design of the pistons and glands. It is recommended that all metal parts of the cylinders, other than those of non-ferrous material, which come in contact with compressed air should be cadmium-plated as, due to the unavoidable moisture in the air supply, the parts rust badly if this precaution is not taken.

The cylinders shown are constructed from steel tubes *A* with cast-iron endplates *B* and *C*. This construction enables tube to be stocked in various diameters and cut off to lengths suitable for the required stroke on the cylinders, and also permits the use of stock patterns for the end-plates. The endplates are held together by studs, the combined strength of which should be ample to take the total load in the cylinder as, in addition to the actual tensile load, stretching of the studs should be reduced to a minimum in order to avoid air leaks.

The pitch-circle diameter of the studs should be kept as small as possible, in order to bring the clamping pressure as nearly as possible on to the ends of the tube. One way of achieving this is to make the studs larger in diameter and mill a flat along one side, which is butted up against the tube.

The piston shown in Fig. 1 is packed with two washers, *D*, either of leather or of moulded composition. It is found that leather, although much used, is not ideal for this work, as it tends to harden and become brittle in use. The remaining parts of the piston may be either of aluminium alloy, for the sake of lightness, or of mild steel. It is essential on this type of packing that the metal washer *E*, between the two leathers, is formed to suit the radius on the leathers as shown. The gland *F*, where the piston rod passes through the top cover, is of the same material as the piston packings.

In Fig. 2 a different type of packing is used, and has proved far more satisfactory than leather. This packing is a mixture of hemp, asbestos, and graphite, and may be purchased ready prepared. The piston is made

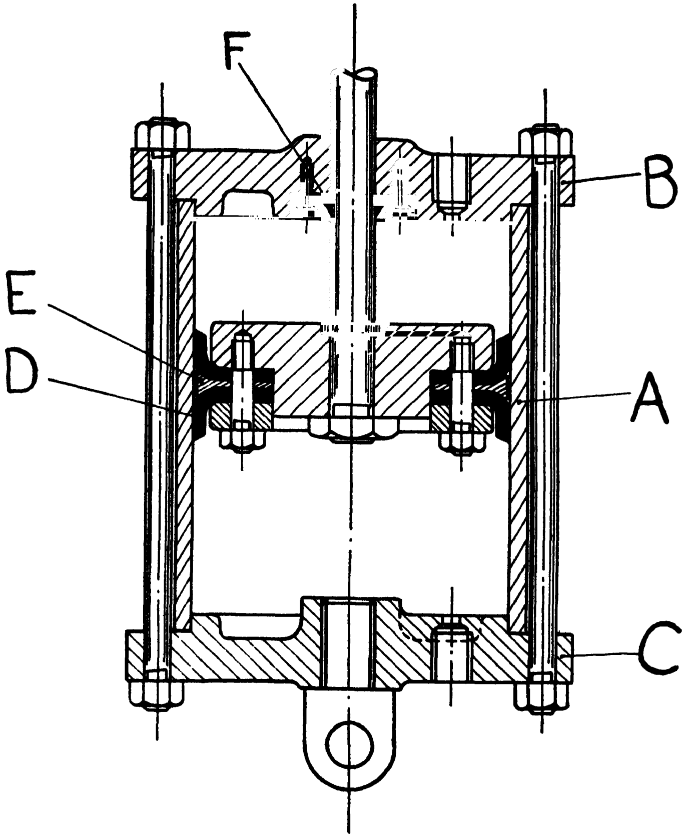


Fig. 1.—Built-up air cylinder (moulded packing)

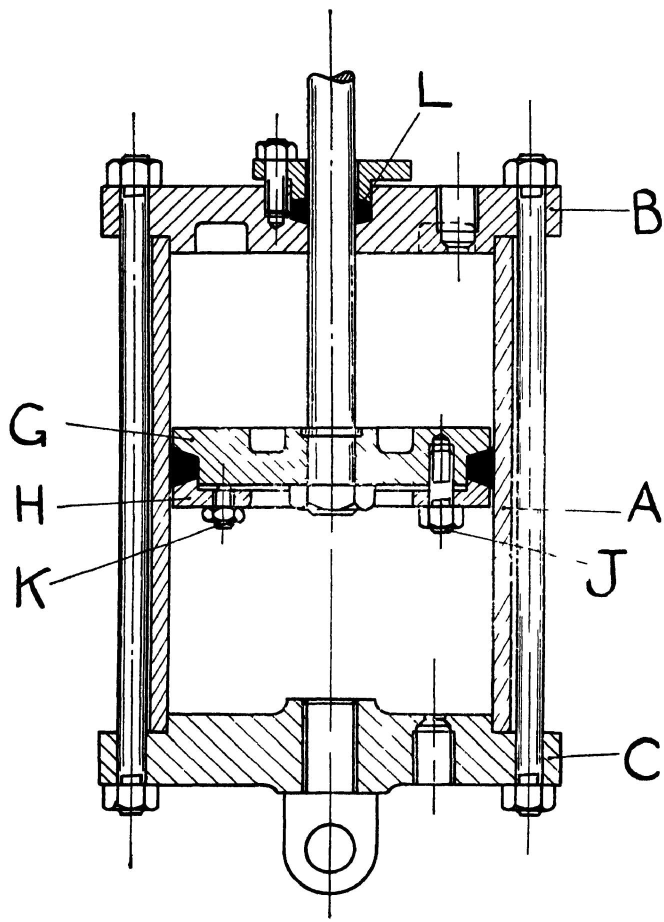


Fig. 2.—Built-up air cylinder (loose packing)

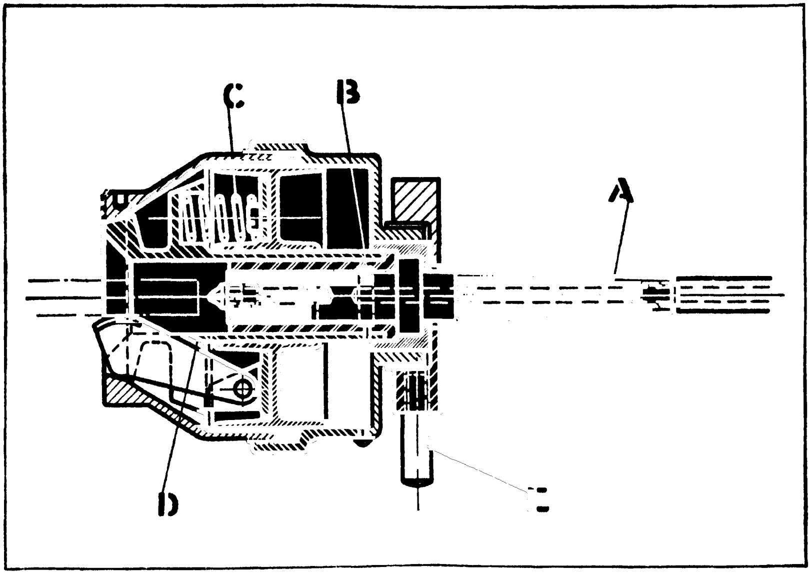


Fig. 3.—Small air chuck

in the form of two washers *G* and *H*, spigoted together, and a groove—in which the packing is wound—is turned between the two. The packing is expanded by tightening the nuts on the studs *J*, but, to enable a solid clamping to be obtained, grub-screws *K* are fitted alternately between the studs to prevent the packing from being expanded until it binds in the cylinder. The piston-rod gland *L* on this cylinder is packed with the same material as the piston.

Small Air Chuck

The small chuck shown in Fig. 3 provides a comparatively cheap form of air chucking, since the cylinder is combined with the chuck, whereas the cylinder and chuck are normally made as separate units. In addition, this type of chuck does not require a drawbar through the machine spindle.

This chuck was designed for a grinding operation on the collar of a shaft, the time for which was only a few seconds, and it was, therefore, necessary that loading and unloading should take place in a minimum of time, and that the work be loaded without stopping the machine. The component, being a swaged piece, varied in length. The chuck had,

therefore, to accommodate this when location had been taken on a fixed centre at the opposite end of the work.

The work, which has one end centred, is inserted into the chuck with the jaws open, the centred end being held on to the tail-stock centre. The action of the jaws closing provides sufficient forward motion to ensure that the work is " home " on the centre.

Air is induced through the taper shank *A*, and thence from the annular groove *B* in the inside bush into the cylinder, pushing the piston forward and closing the three jaws through the medium of the taper ground on the inside of the chuck nose. The reverse motion is obtained through three springs *C*, which exhaust the air through the valve.

The chuck jaws are kept open, ready for the component to be inserted, by the taper shoulder which can be seen at *D* beneath the jaws and half-way along their length. The pin *E* screwed into the gland nut holding the brass bush in place is for driving purposes.

The bore in the air chamber is 4 in. diameter, and the exposed area at 80 lb. per square inch exerts a thrust of 880 lb. between the three jaws. The jaws develop pressure on the work through mechanical advantage equal to three and three-quarter times this figure, less friction, which in this unit is obviously low.

It is found in practice that there is a slight leak of air along the centre-bearing bush, this being sufficient to prevent the entry of any grinding dust into the interior of the chuck.

Air-operated Expanding Mandrel

The mandrel illustrated in Fig. 4 was made for use on a machine with a spindle speed of approximately 900 r.p.m., and due to the high speed it was considered desirable to incorporate a stationary air cylinder rather than a rotating one. The operation is that of rough-turning a cast pot, and tools are provided on the machine for facing both ends to length, boring a register inside the open end, and turning the outside diameter The mandrel consists of a spindle *A*, which is bored to fit the nose of the machine spindle and carries on its outer end a hardened button *B* against which the inside of the component is located.

The actual gripping of the component takes place through the action of the spring *C*, and the air cylinder is used to overcome the resistance of this spring and so release the component. The spring acts through a sliding central plunger *D* on to two jaws *E*, which slide along the tapered ends of the spindle *A* and are thus forced apart to grip the component. Pairs of jaws are made interchangeable for various components and are retained on the mandrel by the spring *F*, which serves also to close the jaws in when the air cylinder comes into operation.

The air cylinder is attached to the back of the machine headstock by two pillars, and the piston *G* operates a push rod which passes through the machine spindle and impinges on to the end of plunger *D*.

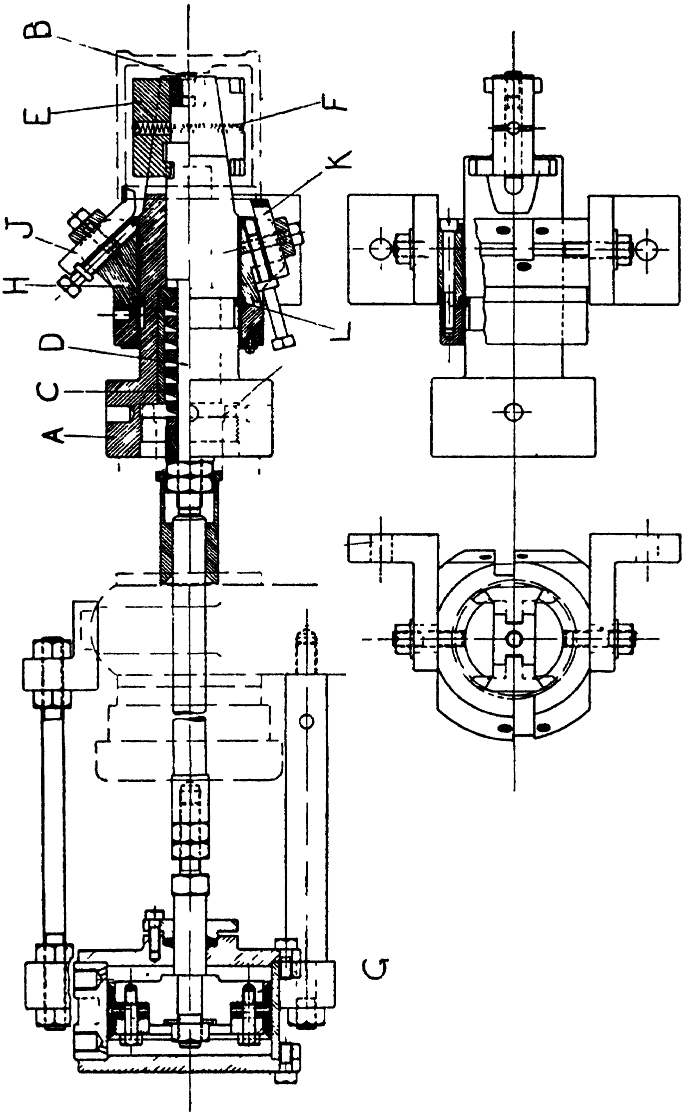


Fig. 4.—AIR-OPERATED EXPANDING MANDREL

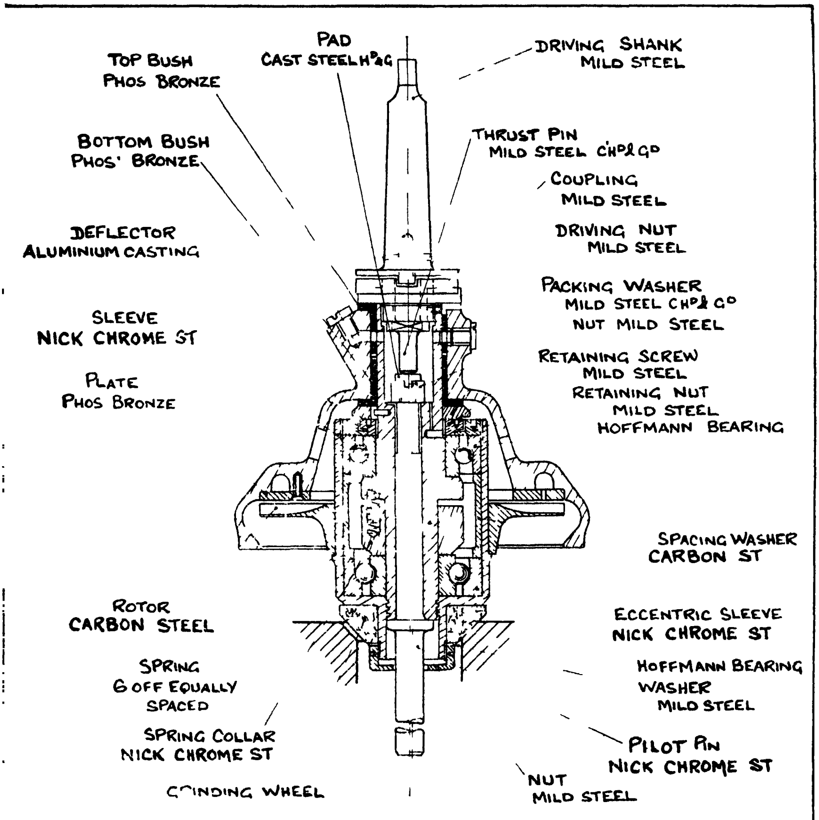


Fig. 5.—AIR DRIVEN GRINDING ATTACHMENT

For facing the open end of the component and machining the inside register a tool block *H* is carried on two brackets which are bolted to the machine saddle. Two tools *J* and *K* are held in this block and adjustment is provided for them. The block is fitted with a central bearing which acts as a centralising device and also helps to support the machine spindle, the two brackets being bolted down after the tool block has been centralised by its bearing.

To restrict the endwise movement of the tool block a hardened collar *L* slides in a groove on the spindle *A*. This groove is fully protected against the ingress of swarf and dirt and, since the groove and the stop-button *B* are located on the same spindle, an accurate location is obtained for facing the end of the component.

Air-driven Grinding Head

Air-driven auxiliary tools may usually be bought as standard, but the tool designer is occasionally called upon to provide a tool for a special application. An example of such a tool is shown in Fig. 5, which is for grinding hardened conical seatings and is used on a drilling machine. The wheel runs at approximately 24,000 r.p.m., and at this speed it is necessary that all rotating parts are carefully balanced. Special attention has also been given to the arrangement of the bearings.

The grinding wheel is driven by a steel rotor mounted on the wheel adaptor. This adaptor runs on two ball bearings of a type suitable for combined radial and thrust loads. The ball cages in these bearings are of a synthetic fabric, since it was found that ordinary brass cages would not stand up to the speed. The two races have different numbers of balls in them, to avoid any tendency for a synchronised vibration between the two. The bearings are spring-loaded by six small springs to take up backlash, this having been found an essential feature, since any backlash which may occur sets up an endwise vibration of the spindle.

Air is supplied through a nozzle attached to the deflector casing, and the stiffness of the supply pipe is sufficient to prevent any tendency for this casing to rotate. The air is fed into the annular groove formed between the casing and the phosphor-bronze plate. In this plate is a series of holes, which are at an angle of 20° to its face and are unequally spaced to break up the frequency between the holes and the grooves in the rotor.

It is essential on any attachment of this type that the number of slots in the rotor should not be a multiple of the number of holes in the nozzle plate, in order that the frequency of the air beats between the two may be above audio-frequency and so avoid the distressing noise which would otherwise result.

Fig. 6 gives details of the various angles for the air feed. The holes drilled round the skirt of the deflector casing are necessary to relieve back pressure, which otherwise tends to blow the oil from the bearings. It will be obvious that the conical wheel cannot be fed straight into the work, but that a line contact must be obtained between the wheel and the work as in ordinary internal grinding practice.

To achieve this, the grinding wheel and rotor are mounted on an eccentric sleeve, which is rotated by the driving shank through a flexible coupling of the Oldham type. Thus the speed of rotation of the drilling-machine spindle is equivalent to speed of work on an internal grinder. The pilot pin runs in a hole in the component and with the taper driving shank serves to maintain the alignment of the attachment.

Automatic Drill Jig

The operation of many jigs may be speeded up by eliminating hand clamping. The jig illustrated in Fig. 7 has been found particularly useful

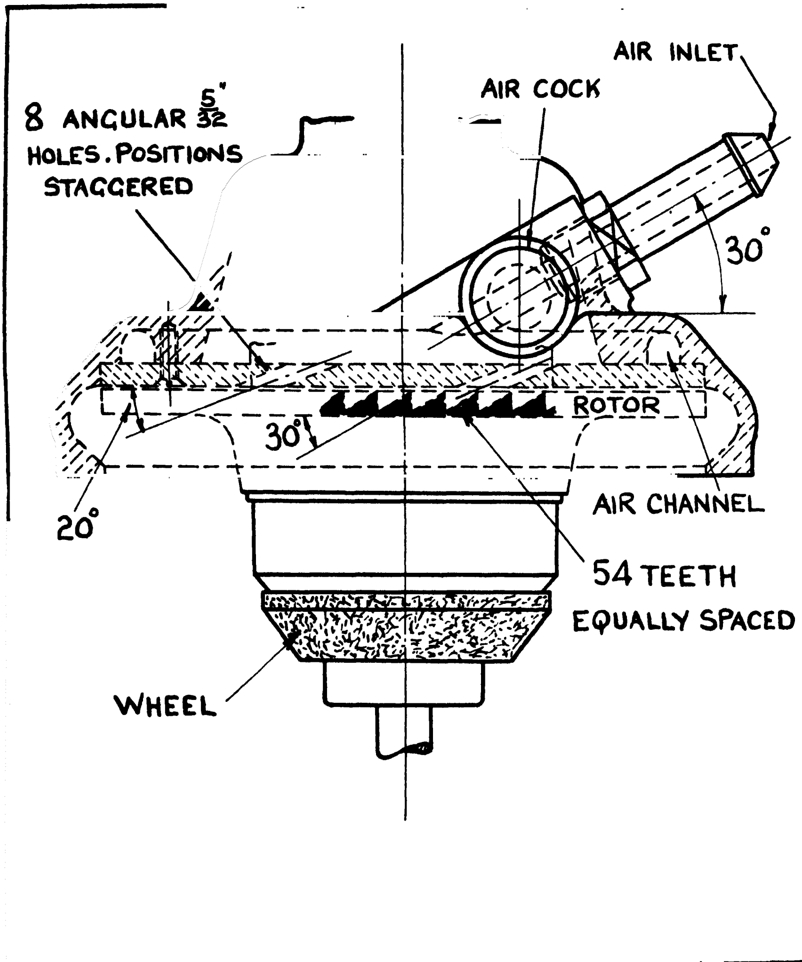


Fig. 6.—AIR-FEED ARRANGEMENT FOR GRINDING ATTACHMENT

for the rapid drilling of holes round the circumference of tubular components.

The clamping is air operated, and the controlling valve is operated by a foot pedal placed near the floor. On the spindle locating the component is an index plate *A*, having a number of teeth corresponding with the number of holes to be drilled. The lever *B* engages with the index plate

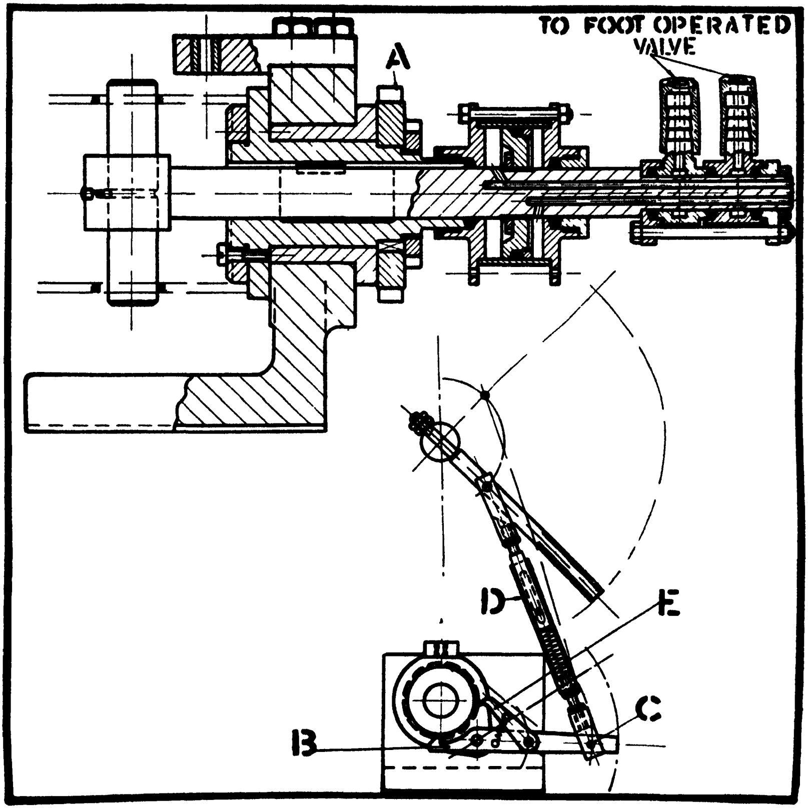


Fig. 7.—AUTOMATIC DRILLING JIG WITH AIR CLAMPING

and registers the position. This lever also, at the point *C*, is attached to the drill-press feed lever through an adjustable link *D*.

The operation of raising the lever on the drilling machine lifts the lever *B*, and the pawl *E* is raised, consequently revolving the index plate sufficiently to allow the lever to register the next position. Thus the indexing becomes automatic. The link between the two levers is spring loaded, thereby compensating and loading the locating lever *B*.

Air-operated Toggle Presses

Air may be used as the power medium in the operation of toggle presses. The next two examples show applications to which these simply constructed presses have been put. A feature of such presses is the

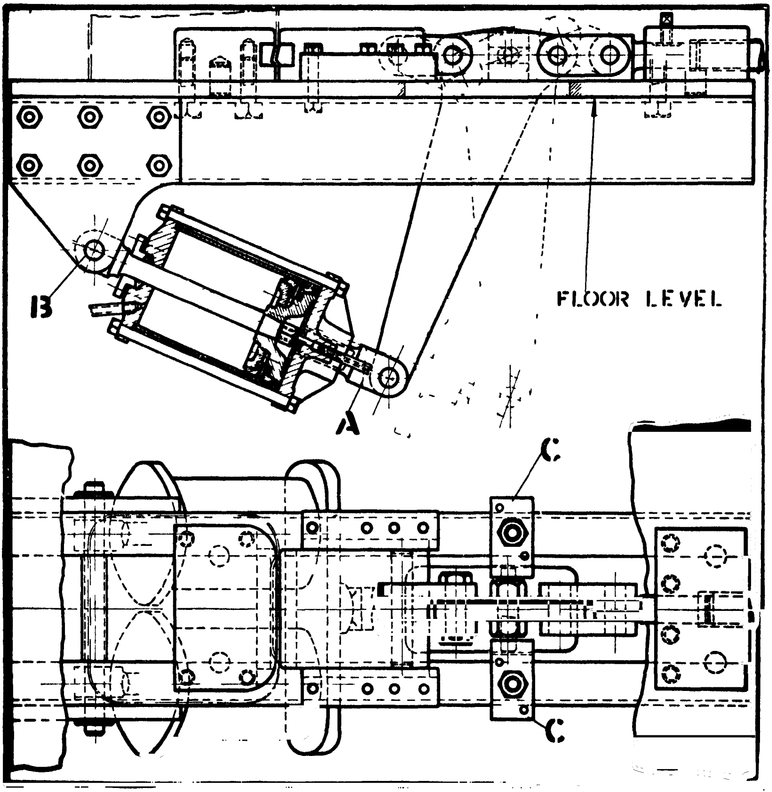


Fig. 8.—Horizontal air-operated toggle press

relatively high pressure obtained in relation to their size. The toggle principle used ensures that the pressure is applied gradually and is at its greatest on completion of the operation.

The press shown in Fig. 8 is used in the horizontal position, with the cylinders and operating lever below the floor level, which is the most convenient position for pressing a corrugation in the four sides at either end of a rectangular tank 6 ft. long. No lifting is required. The tank can be tilted on one edge and so over the die, standing on end whilst being pressed. The head formed is used as a buttress for endplates, which are soldered in position.

Two air cylinders operate the press and both cylinders are mounted on one head, into the centre of which the fork endpin *A* is screwed. This

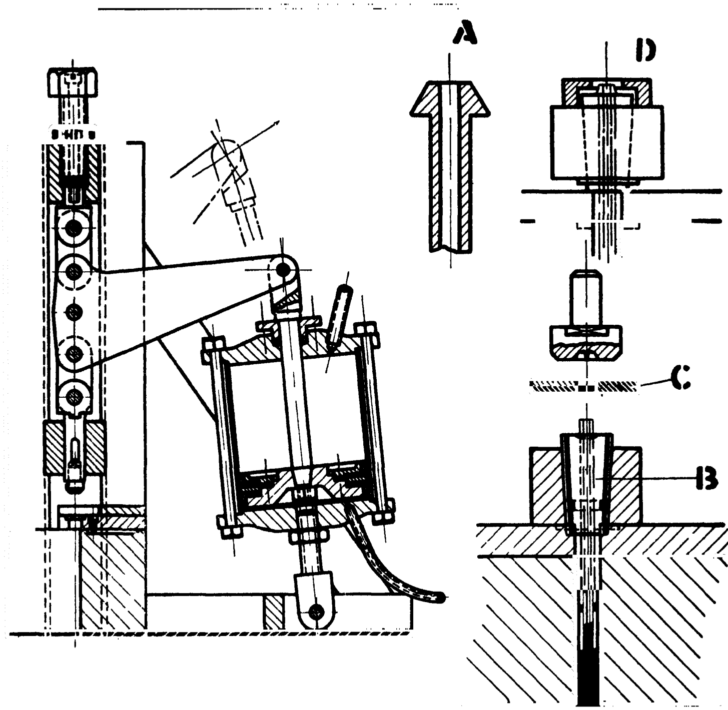


Fig. 9.—Vertical air-operated toggle press

construction is used to eliminate side thrust, triangular lines of force bringing about straight-line movement. The cylinders pivot on hinged bolts *B* coupled to the base.

Air for the closing stroke of the press is admitted at the top of the cylinder through a $\frac{3}{32}$-in. hole, to avoid too-rapid down stroke. The return stroke is operated from the opposite end of the cylinder, the air entering through a larger bore, increasing the speed to save time. The centre-line positions for the lever are maintained by a pin which rides in the blocks *C* on either side of the frame.

At 80-lb. pressure per square inch, the two 5-in. cylinders develop a thrust of 3,000 lb., and with the toggles at 11° 30′ from the closed position a mechanical advantage of $7\frac{1}{3}$ to 1 is obtained, the press at this point

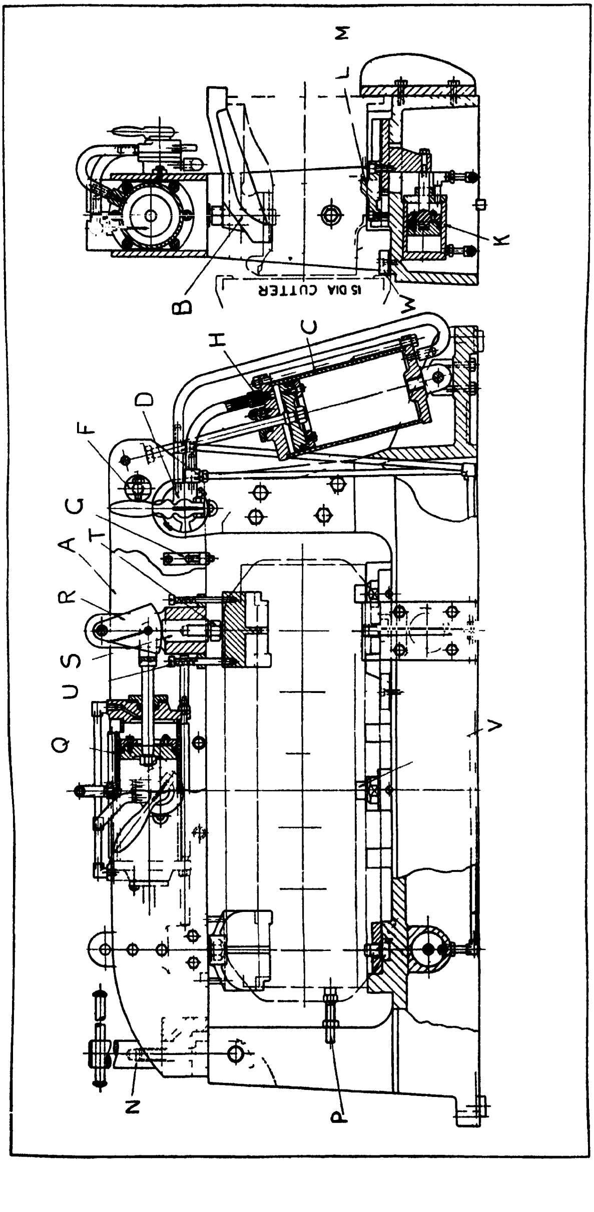


Fig 10 — AIR OPERATED FIXTURE

applying approximately 10 tons. With the toggles at 3° from the closed position, the mechanical advantage obtained is 28 to 1, or approximately 38 tons, and the importance of the above figures becomes manifest when the indentation required is of a deep nature.

It is therefore essential to ascertain that there is sufficient pressure available to overcome the resistance of the material at the commencement of the pressing operation.

The example illustrated in Fig. 9 is similar in construction to the previous one, except that there is only one operating cylinder instead of two, and the press is used in a verticle position for pressing up the ends of steel tubing so as to form an adequate seating for an oil-pipe union nut. The form produced is shown enlarged at *A*.

It was determined that a pressure not less than 15 tons would be required, and the press was arranged, therefore, to give this figure with the toggles approximately 3° from the vertical position.

The tubes are held in a collet *B*, and a downward stroke of the press—with a washer *C* over the tubing—closes the collet on to the tube, after which a second stroke of the press—with the washer removed—up-ends the tube itself. For ejecting the tube from the collet, the register plate is indexed to a second position by a lever alongside the collet arrangement, and a third stroke of the press forces the outer ring off the collet, so freeing the tubing. This is done by the aid of the collar shown at *D*.

Air-operated Fixtures for Milling

The air-operated fixture shown in Fig. 10 is one of a series of four designed for progressive milling of four faces on a large casting. The fixtures are mounted in line on the stationary table of a line milling machine, and a 15-in.-diameter cutter is traversed the length of the table. Each fixture is arranged for milling one of the faces of the component, which is moved from one fixture to the next until the milling of the four faces is completed. In this way there is no delay for loading and unloading. The cutter traverses the fourth fixture first, after which the component therein is removed and the component in the third fixture is transferred to the fourth, and so on as the cutter passes the four fixtures, the cutter then receding from the work and being fed back on a fast motion to the other end of the table.

The fixture illustrated is the one for milling the fourth or final face, and is completely air operated. To facilitate loading the component into the fixture, the beam *A* carrying the clamps *B* can be elevated to the vertical position by a 6-in.-bore air cylinder *C*, which is shown in detail in Fig. 11. The effort exerted by this cylinder is a little in excess of that required to lift the beam steadily. The two-way valve *D* controlling the air flow to the elevating cylinder is mounted centrally over the pin *E* on which the beam is pivoted.

By the action of suitably disposed stops *F* and *G* mounted on the beam,

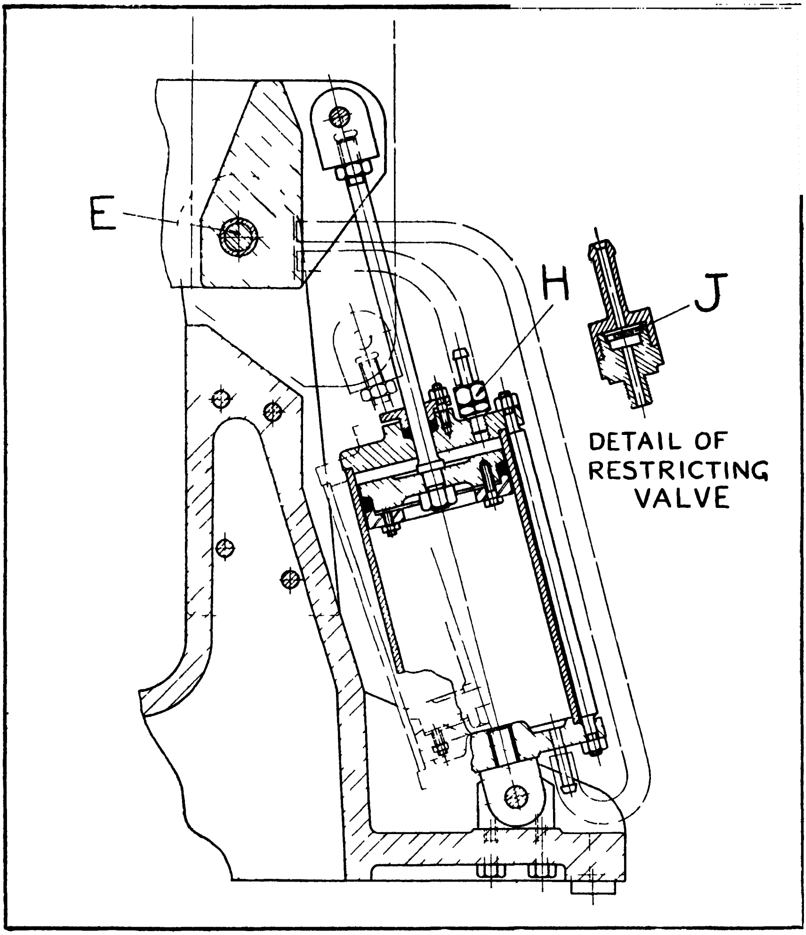


Fig 11 —Detail of elevating cylinder for air operated fixture

the lever of the valve is operated by the movement of the beam at or near the end of its travel, so shutting off the supply of air to the cylinder. At the same time the exhaust port to the atmosphere is closed, shutting off the air escaping from the cylinder and forming an air cushion at the end of the stroke of the piston.

This is even more desirable on the downward movement of the beam—or upward stroke of the piston—to prevent the beam from crashing on to

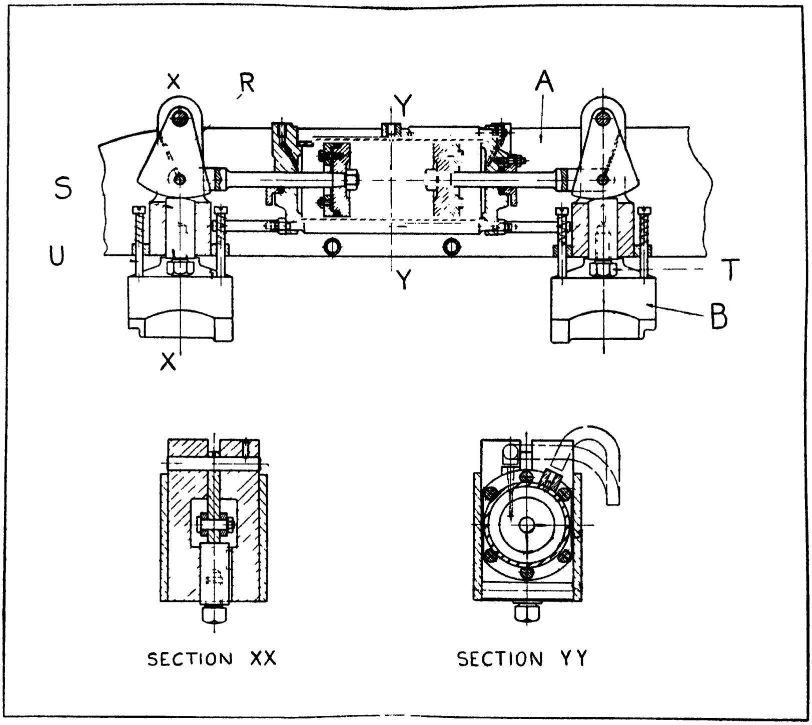


Fig. 12.—Detail of clamping cylinder for air-operated fixture

its support. To perform this function there is incorporated in the air line at the top of the cylinder a valve *H*, which allows a greater volume of air to flow into the cylinder for lifting the beam than can escape from the cylinder when the beam is being returned to its support. This restricting valve is shown in enlarged detail in Fig. 11, and consists of a casing in two halves which are screwed together.

The two small cylinders *K* located on the underside of the fixture provide, through the medium of sliding dogs *L*, means for pushing the component on to the two locating brackets *M* which line up the previously milled faces parallel with the fixture. These small cylinders are connected in the same air line as the cylinder for elevating the beam. Thus, when the component is lowered on to its supports it is pushed into position against the locating stops as soon as the air valve is operated by hand to bring the beam down. With the beam in position it remains to swing the

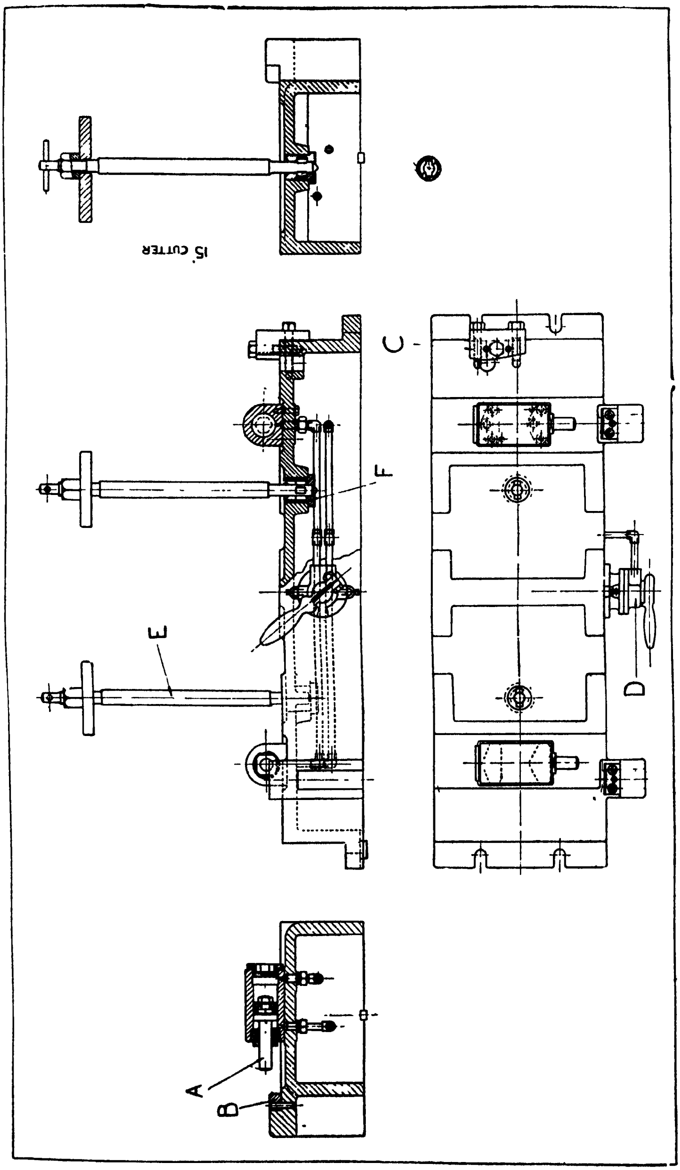


Fig. 13.—FIXTURE WITH AIR-OPERATED LOCATING PLUNGERS

clamp bolt N into place and lightly tighten the tommy nut, care having been taken when loading that the component is butting endwise on to the screw P which takes the thrust of the cutter.

Clamping is effected by a duplex air cylinder Q, shown in detail in Fig. 12, mounted on the beam. The cylinder has two pistons which are forced apart, to operate the clamps B, when air is admitted between them. The pistons are connected to two cams R, which exert pressure on plungers S butting on to the clamps. Adjustment is provided by screws T, and the clamps, which are allowed to float, are lifted from the work by springs on the shouldered screws U.

It will be appreciated that should the air line fail, the clamps are not released, as the cams have a locking angle which ensures that they are "non-returnable." In actual fact, considerable reverse pressure is required to release them, air being applied to the outer ends of the pistons for this purpose.

To remove the component from the fixture, the air valve is operated to release the clamps, the tommy nut is loosened, and the clamp bolt swung clear. Then the other air valve is operated to raise the beam and return the two locating slides. The component is then lifted clear with an air hoist, and the component transferred from the next fixture.

Three jacks V are provided to support the component against the clamping thrust and to prevent the tilting effect which would be otherwise introduced. The jacks are spring loaded on to the component, and are locked in position by hand levers. A block W is screwed to the base of the fixture and is used for setting the cutter relative to the fixture, a 2-mm. slip gauge being used between the block and the cutter.

It will be noticed that the studs which secure the endplates on the two larger air cylinders of this fixture are increased in diameter between the endplates. This is for the purpose of avoiding, as far as possible, stretching of the studs due to the load on the cylinder, and is added as a refinement because both of these cylinders require fairly long studs. Flats are milled on the studs in order that the pitch diameter of the holes is not increased.

The fixture shown in Fig. 13 is for the second operation on the same component. Air is used on this fixture to operate the small pistons A, which push two spotting points on the component against hardened locating blocks B. The thrust of the cut is taken against the block C, and it will be noticed that a hole is drilled through the casting at the locating point to allow for the clearance of any particles of swarf which might tend to collect there. The plungers are both operated by the valve D. Clamping on this fixture is effected by the use of two bolts E, which pass through holes in the component and locate in bayonet slots in bushes F pressed into the casting. It is not necessary to provide air clamping on this fixture, since the operator has ample time in which to remove the two bolts. In addition, the construction of the fixture is both simplified and cheapened.

Chapter XXI

NEGATIVE RAKE MACHINING

ONE disadvantage that has retarded the use of Tungsten Carbide Tools for many machining operations has been the brittleness of the material and its consequent inability to stand up to certain machining operations, particularly where interrupted cuts were required to be taken. This weakness has been due to the stresses set up in the cutting tip of the tool, brought about by the rake and clearance angles. To overcome this difficulty tools have been introduced having negative cutting rakes.

The effect on tools having such rakes is to introduce a compressive stress to the tool point against the bending or tensile stress on a tool having a positive cutting rake. Thus it is possible to take advantage of the high compressive strength of the tungsten-carbide alloys and to overcome their weakness in tension or bending. The following advantages are therefore claimed in the use of cutting tools having negative rakes :

(1) The compressive strength of cemented carbide is used to full advantage.

(2) By using negative-raked cemented-carbide tools on milling and turning operations, full advantage may be taken of the potentialities of this material, and cutting speeds and feeds increased up to the maximum recommended.

(3) The resulting finish on the work is very much improved over that obtained with positive-raked tools and compares in many cases with the finish obtained by surface grinding.

(4) Owing to the greatly increased cutting speeds and feeds, the heat generated during cutting remains in the chips or swarf (which are removed from the work much more rapidly). Consequently the workpiece and the cutter remain cool, with the advantage that there is little or no distortion on the workpiece.

To illustrate the above remarks regarding strength of cutting edges, the diagrams in Fig. 1 show at (*a*) the cutting edge of a tool having positive rake, and at (*b*) the cutting edge of a tool having negative rake. Both tools are shown in the process of removing a chip from the workpiece.

It will be seen that in the tool shown at (*a*) the thrust of the cut is directly through the cutting edge of the tool, introducing a bending load on the cutting edge which results in a tensile stress causing in many cases a fracture of the cutting edge. The direction of thrust in the tool shown at (*b*) can be seen to be directly through the tool shank, resulting in an

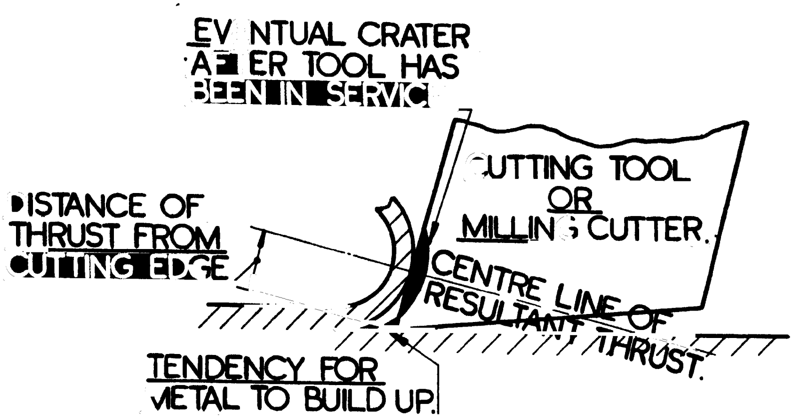


Fig. 1 (a).—Cutting action of tool with positive rake

almost direct compressive load which the tungsten-carbide material is capable of sustaining.

There is, on any type of cutting edge, a cratering effect due to the abrasion of the chips being removed, and it will also be seen from the diagram that this crater is further removed from the cutting edge on the negative-rake tool.

As this crater eventually weakens the cutting edge, it is an advantage for the crater to be produced as far from the cutting edge as possible.

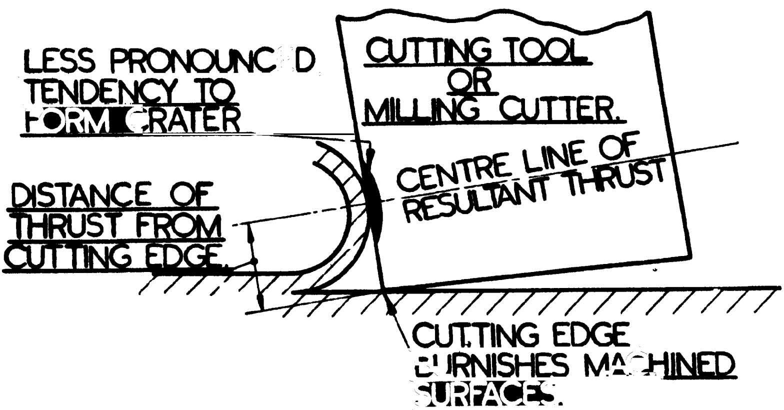


Fig. 1 (*b*).—Cutting action of tool with negative rake

Face-milling Cutters

Due to the considerable amount of shock in a milling cutter, the development of such cutters having tungsten-carbide tipped blades has been retarded owing to the weakness of the normal positive-rake blades, but milling is an ideal application for tungsten-carbide tipped blades having negative rakes.

The following paragraphs indicate the steps to be taken in designing a milling cutter for a particular application.

Firstly, it must be borne in mind that as metal is being removed from the workpiece at a very much faster rate, it will be necessary to apply more horse-power to the cutter spindle of the milling machine. In addition, the horse-power required to remove a given amount of metal with a tool having negative rake is approximately 15 per cent. greater than the horse-power required to remove a similar amount of metal with a tool having positive rake. With these two factors in mind, it is necessary to determine the horse-power available on a particular machine and to design a cutter and decide upon speeds and feeds within the capacity of the machine. In some cases it has been found necessary to fit larger motors to the machines, but this step should only be taken after careful consideration of the basic design of the machine and the method of transmitting torque from the driving motor to the machine spindle. It is also desirable that the machine is fitted with some form of backlash-eliminating mechanism on the table, as climb-milling is adopted on many operations using these cutters.

Material	*Tensile Strength tons/□"*	*Cutting Speed ft./min.*	*Metal removed cubic ins. h.p./min.*
Mild Steel	30–35	850	0·75
Carbon Steel	40	800	0·75
Alloy Steel	40–50	700	0·75
Alloy Steel	50–60	650	0·8
Alloy Steel	60–70	550	0·8
Cast Iron	15	500	0·8
Cast Iron (Alloy)	20-30	500	1

Fig. 2.—CUTTING SPEEDS AND RATES OF CUTTING VARIOUS MATERIALS WITH NEGATIVE RAKED TOOLS

The table shown in Fig. 2 indicates recommended speeds at which various materials may be cut, and also shows approximate figures for metal removed in cubic inches per minute per horse-power. The diameter of the cutter will, of course, depend on the application, and is obtained from the size of the face to be milled: for example, a 4-in. face will require a cutter approximately 6 in. in diameter. Thus, having determined the diameter of the cutter and decided upon a surface speed in feet per minute, the revolutions per minute of the cutter spindle may be decided upon.

Special consideration must be given to the problem of rigidity in supporting and clamping the work. It should be understood that as the work is being cut at a higher speed, these considerations are even more important than when designing milling fixtures for use with conventional cutters.

Referring again to the table shown in Fig. 2 it will be seen, for example, that the removal of ·75 cu. in. of mild steel per minute requires approximately 1 h.p. From these figures the volume of metal which may be safely removed per minute, according to the horse-power available on the machine, may be determined by the following rules:

Cubic inches removed per minute = the horse-power available on the machine × cubic inches removed per horse-power per minute.

For example, if 10 h.p. is available on a machine engaged on machining mild steel 30 tons per square inch tensile, the safe rate of metal removal is given by 10 × ·75 = 7·5 cu. in. per minute.

Having obtained this figure and knowing the area of the face to be machined on the workpiece and the depth of cut to be taken, a simple calculation gives the rate, in feet per minute, at which the workpiece may be fed past the cutter. This rate or table feed may be determined by the following rule:

$$\text{Table speed in inches per minute} = \frac{\text{cubic inches of metal removed per minute}}{\text{width of face to be machined} \times \text{depth of cut}}.$$

It remains now to determine the number of teeth required in a cutter for a particular application. The amount of metal removed by each tooth is given by the rule:

$$\text{Feed per tooth in inches} = \frac{\text{table speed in feet per minute} \times 12}{\text{R.P.M.} \times \text{number of teeth}}$$

It is advised, however, that in practice the cutter is designed to give a feed per tooth varying from ·003 in. to ·010 in., and the feed per tooth should not be less than the smaller of these figures.

It will be seen from the diagrams given in Fig. 3 that the greater the feed per tooth, the farther removed from the cutting edge is the point of impact of the tooth with the work. It is therefore an advantage from the point of view of tooth strength to have this impact as far removed from the cutting edge as possible, and this also tends to reduce weakening of the cutting edge due to cratering. It is necessary, therefore, to deter mine the feed per tooth bearing in mind the advantage of having the point of impact removed from the cutting edge, but at the same time considering that an unnecessarily large cut per tooth will tend to cause hammering on the cutter.

An empirical rule indicates that the number of teeth in a cutter should exceed the number of inches in the diameter by two. As an example this gives 10 teeth in an 8-in. diameter cutter, but this rule takes no consideration of the amount of metal removed per tooth.

Cutting Rakes

In determining the cutting rakes on the teeth, there are two angles to be considered, these being (*a*) Radial rake, and (*b*) Axial or Helical rake.

Radial Rake.—Fig. 4 shows diagrams of cutters having positive and negative radial rakes, and this angle again depends on the hardness of the material. For general work on reasonably hard materials a negative rake of up to 10° is recommended.

The best rakes to be used for a particular application can be determined by experiments, but for general purpose work cutters may be stocked with up to 10° negative helical rake, with radial rakes from 0° to 10° negative.

Axial or Helical Rake.—This angle, as shown in Fig. 5, gives what is known as the cutting angle on the cutter or tool and may be made up to about 10° negative, depending on the hardness of the material (the angle increasing as hardness increases). Undue negative rakes should be avoided and it should here be pointed out that on non-ferrous or soft materials there appears to be no advantage in using negative rakes, which only add to the power required to remove a given amount of metal. It would appear that a cutting tool with a negative rake would tend to jam the chips between the cutting edge and the work, but this is not so, as due to the high speed of chip removal and the greater pressure on the chips, these are flung clear of the cutting edge with greater velocity than on conventional tools. Owing to the high speed of chip removal, it is necessary when determining cutting angles and laying out the cutter blank to allow large chip clearances so that there is no impedance of the clearance of the chips.

Bevel Angle and Corner Radius

In order to ensure further that the impact of the cutter and the workpiece occurs at a point removed from the cutting edge, two additional

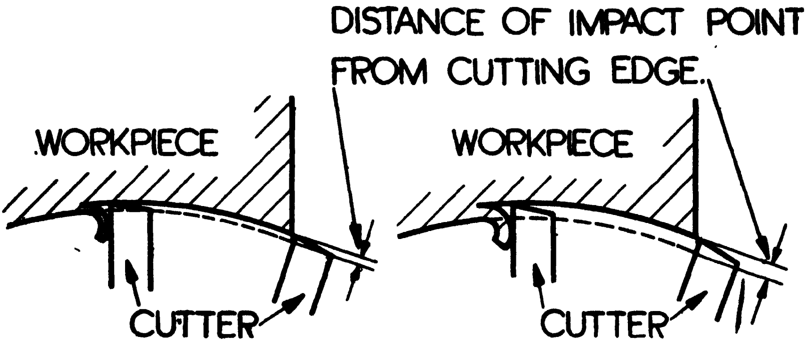


Fig. 3.—Effect of depth of cut per tooth on impact point of cutter blade

precautions are taken in design. Wherever possible a bevel angle should be incorporated in the cutter as shown in Fig. 6 ; for most purposes an angle of 15° is satisfactory and gives the cutting edge an adequate lead in. If it is required to mill up to a square shoulder a bevel angle cannot be used, and in consequence care should be exercised and trials made to

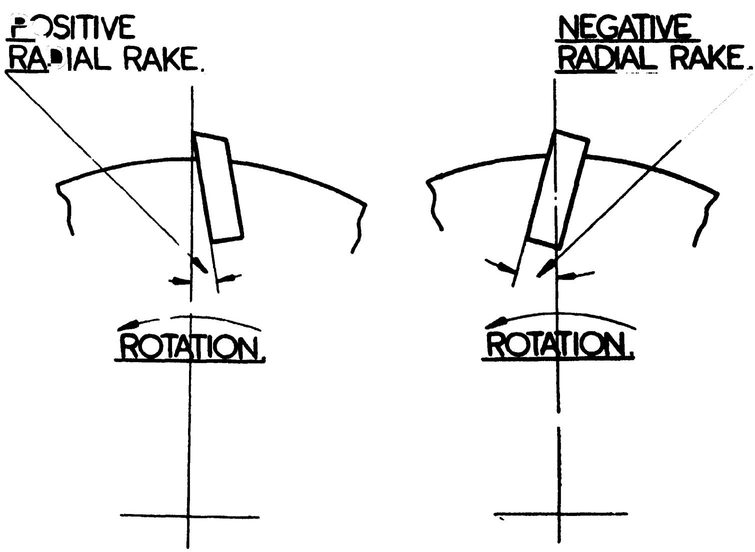


Fig. 4.—Positive and Negative radial rakes

determine the correct cutter to be used. When such is the case and the elimination of the bevel angle is necessary, it would be wise to increase the radial negative rake and the negative axial rake. This will throw the point of impact still farther from the cutting edge, which is likely to be weakened by the hammering due to the absence of a bevel angle.

The cutting-tip of the cutter should always be provided with a corner chamfer of at least $\frac{1}{16}$ in. at 45°, in order to strengthen the extremity of the carbide tool steel. In addition, the chamfer—or a comparable radius—should be relieved at an angle 1° less than the main peripheral relief.

Types of Cutter Blanks

The three main types of cutter construction are as follows:

1. *Cutters with Inserted Tipped Blades locked mechanically.*—Where the convenience of replacing chipped tools is of paramount importance without regard to the initial cost of the cutter, use may be made of the type having a solid steel body, with tungsten-carbide tipped blades locked mechanically into the body. The design of such a cutter body should be of the sturdiest proportions in order to damp out vibrations created at the cutting edges.

2. *Cutters with Inserted Mild-steel Tipped Blades welded in position.*—Cutters of this type are cheaper in construction than those with mechanically locked blades, but suffer from the inconvenience of difficulty in replacing chipped blades. They have been used with success, however, as the welded construction is conducive to greater rigidity than the

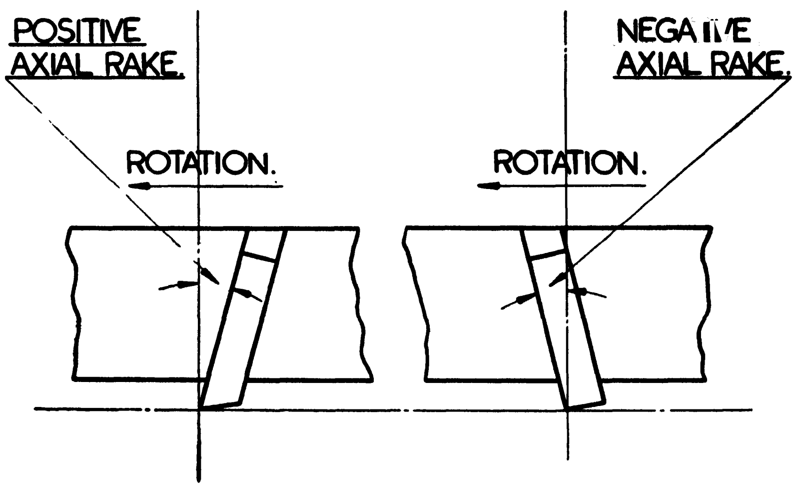


Fig. 5.—POSITIVE AND NEGATIVE AXIAL RAKES

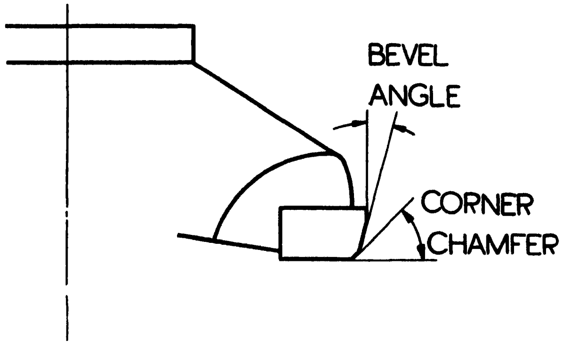


Fig. 6.—BEVEL ANGLE AND CORNER CHAMFER

mechanically locked blades, and the consequent lower risk of tool breakage helps to offset the difficulty of servicing.

3. *Solid Meehanite Cutters with Tipped Teeth.*—The resilient properties of meehanite iron castings are used to advantage in the body of a negative-rake milling cutter, where it is required to absorb and damp out vibrations. The tool tips are brazed directly to the casting and can be replaced when worn or chipped by melting the brazing and substituting new tips.

In general it should be pointed out that milling cutters having teeth with negative rakes are only recommended for milling operations where the amount of metal to be removed warrants the cost of the cutters, which is considerably greater than high-speed steel cutters, whatever design is adopted. Apart from face-milling operations, these cutters have been used when machining slots from solid and for other similar heavy operations.

When designing fixtures for use with negative-rake cutters, it should be remembered that as the cutting time is reduced considerably, the loading time becomes more important and fixtures should therefore be designed for ease of loading and clamping, air clamping providing a quick and efficient medium.

Turning Tools

Turning tools having negative rakes give longer life than tools with conventional positive rakes. Such tools do not, however, give the advantage of increased cutting speeds obtained with the milling cutters referred to above, as it has already been possible on most turning jobs to take full advantage of the high cutting speeds of which tungsten carbide is capable. Where intermittent cutting occurs, however, tools having negative rakes prove of great advantage in standing up to the shock load, their application then approximating the conditions obtained with milling cutters.

Turning tools usually have negative top rakes varying from 5° to 10° for general work, although angles up to 25° have been used. As in the case of milling machines, it is essential to ensure that the lathes used are

sufficiently rigid and in good condition, and also that driving motors of sufficient capacity are fitted.

Turning tools should have chip-breaking grooves ground in them as referred to in an earlier chapter. This is important owing to the high speed at which the swarf leaves the tool.

All machines using negative-raked tools or cutters should be well guarded to restrain the chips. Owing to the high speed of removal, these have a greater tendency to fly about the shop than when using normal tools. Most negative-raked tools are used dry with no coolant, otherwise there is a tendency for the cutting edges to crack as the chips leave the tool at a temperature approaching or actually at red heat. If a coolant is used it must be supplied in ample volume to obviate any tendency for intermittent cooling and heating of the cutting edges, and it must flow directly on to the cutting edges.

Chapter XXII

TRANSFER MACHINING

THE good production engineer is continually striving to increase output, particularly in the case of the so-called " mass production " industries, and one of the latest developments in this field is the introduction of the " transfer machining " system. In order fully to understand the aims and benefits of this scheme, it is first necessary to survey some of the general problems associated with production engineering, and the manner in which attempts have been made in the past to overcome them.

General Problems

One of the earliest efforts to raise output consisted, naturally, of increasing speeds and feeds to their maximum, and of the introduction of extensive jigging, both aimed at reducing machining times : the former was given a considerable fillip by the introduction of cemented carbides. The position was finally reached where further reduction of machining times was practically impossible, and it became necessary for the production engineer then to turn his attention to other factors.

One of the most important of these was the reduction of the time occupied by handling the components as they passed from operation to operation, this being combined with the equally important subject of reducing operator fatigue to a minimum so that a steady output could be maintained : because of fatigue there was a tendency for output to fall fairly considerably towards the end of the day. To do this, means were introduced to eliminate the need for lifting heavy work and fixtures, these including the simplification of clamping by the large-scale introduction of air-operated clamps, cam clamps, quick-action clamps, and other devices. Extensive use was also made of conveyors for transporting work from station to station : in many cases these were arranged to deliver the work at the level of the machine table so as to avoid the need for lifting.

At the same time another important problem arose—i.e. the conservation of floor space. In most factories there is a considerable shortage of floor space, and thus it is imperative to bear this in mind when introducing any new methods or layouts. In many factories, considerable floor area is occupied by work stacked between operations, i.e. between the machines, and thus a partial solution could be effected by reducing or, if possible, eliminating this wastage. This problem was to a large extent

solved by the use of conveyors. In some cases these were even run up to the roof in order to provide sufficient length to carry a large enough " float " of components to ensure that no machines were ever " starved."

Another obvious remedy was to place machines more closely together. but maximum saving in this direction was not achieved until the introduction of the transfer system, described later.

Flow Production

Earlier attempts to solve the above problems led to the introduction of such time-saving developments as laying down lines of machines and equipment arranged in sequence of operations so that the work " flowed " straight on from one to the other—i.e. " flow production." Amongst other benefits, this scheme avoided the wastage of time and effort formerly expended in transporting the work backwards and forwards from one operation to another. Where conditions were suitable, this scheme was improved by linking the machines or processes by some form or other of conveyor, either static or moving.

In addition to increasing output, flow production largely solved the problems of operator fatigue and conservation of floor space, the latter by (1) the more compact arrangement of the machines and (2) the reduction of work stacking between machines. Flow production meets the requirements of a large proportion of the engineering industry, and is extensively employed at the present time.

Automatic Work Handling

For a time it appeared that the production engineer had achieved his goal, and no further reduction in handling times, operator fatigue, or floor space was possible. However, in recent years yet another problem arose—i.e. shortage of labour—and this caused him to seek ways of reducing, or even almost completely eliminating, the need for manual handling of the work. This would involve automatically feeding the work to the machine, automatically operating the machine, and automatically unloading it.

This ideal was achieved in stages, the first consisting of mounting a number of machine heads along or around a common table, and then manually sliding the work along the table from station to station, and loading and unloading them into the fixtures, often with the aid of lifting devices. This scheme, known as " hand transfer machining," was then improved by the provision of means for automatically moving, loading, and unloading the work, a system now known as "automatic transfer machining." It should be noted that the basic difference between this scheme and the ordinary automatic machine lies in the fact that the work is automatically transferred from station to station ; also, that it is capable of dealing with large and heavy components of awkward shapes.

The next logical development was to build a number of such automatic transfer machines into a single line to perform a complete sequence of operations, or even completely machine the component. This application of automatic transfer machining is now often termed "automation." There is no limit to the type of plant that can be included in the system. Although it is largely employed for lighter operations such as drilling, tapping, reaming, spot facing, etc., it can easily be linked with the very heaviest machines, such as broaches, boring machines, heavy facing mills, presses, etc. It is even possible to incorporate means for automatic inspection of the operations as they are performed. The system is by no means limited to machining : extremely efficient lines have been developed for assembly purposes, and for press shop use.

There is another scheme which is half-way between flow line production and automation. Known as "semi-automatic transfer machining," it comprises a combination of the principles of the two systems. Such a layout is described later.

The decision as to which system to employ is governed chiefly by the output required, although other factors—such as the shortage of labour—may also influence the choice. In general, it is a fairly safe principle to state that if line flow production does not give the required output, consideration should be given to adopting the semi-automatic transfer system. If still higher production is required, the advantages of automation should be studied.

Advantages of Transfer Machining

Summarising the advantages of transfer machining, these are as follows :

(1) It will handle components of extremely awkward shape, size, or of any weight.

(2) It is flexible and can be arranged to suit modifications in the design of the components.

(3) Apart from feeding and unloading the line, the need for operators can be reduced considerably or, under particularly favourable conditions, even eliminated.

(4) Operator fatigue is practically eliminated.

(5) Output is considerably increased : the speed of output can be easily varied to ensure balanced production with other departments.

(6) Control of the work passing through the shop is simplified.

(7) Considerable floor space is saved by the elimination of inter-operation stacking and the close grouping of machines.

(8) The life of cutting tools may be considerably extended, thus reducing replacement costs and hold-ups due to resetting.

(9) Because of their simple basic design, should the component become obsolete the plant can be disassembled and rebuilt to suit other workpieces.

It will be seen that all the important requirements mentioned earlier are covered in the above list, plus certain additional benefits.

Item (8) is of particular interest, as it refers to a reverse of the procedure employed in the past. Until the introduction of transfer machining it has always been the policy to use the highest possible feeds and speeds in order to reduce production times. With transfer machining, however, it is an essential requirement that all operations occupy the same "time cycle." Consequently, the time cycle of all machines is controlled by the longest operation on the line. Thus, if all the tools work at their maximum speeds and feeds, as in other forms of machining, those engaged with the shorter operations will have to "idle" for much of their cycle. For this reason the short-operation tools are often run at much lower speeds and feeds than in the past, this being done without slowing production at all. In some cases it is found that this increases tool life between grinds by as much as 300 per cent.

In regard to item (2), it is generally quite an easy matter to insert extra machines in the line in order to deal with any design modifications of the component which might arise in the future, and it is quite common practice to leave spaces or idle stations in the line for this purpose. It will be realised, however, that the line is specifically laid out for the production of one particular component, and cannot be used for other types of work. However, in some cases it is possible to lay out the line to handle other components, but these must be of a generally similar type to those for which the line was originally designed. An example of this is given later.

Item (6) refers to the fact that the output from the line can be increased or reduced merely by altering the time cycle of the longest operation. If output is to be increased in this manner, this may involve the employment of extra operators. Conversely, if output is to be reduced, it may be possible to dispense with one or more operators and share their work amongst the remainder.

Machine Design

It is impossible to give any hard-and-fast rules regarding the design and layout of transfer machining lines because these will differ according to the component involved and the nature of the operations to be performed. The basic principles are, however, similar in all cases.

In general, the machines consist of simple heads incorporating minimum mechanism and devoid of many of the refinements provided on ordinary equipment. Many incorporate provision for multi-spindle attachments. Most are provided with hand feed for setting purposes, automatic feed and withdrawal mechanism, and pick-off gearing for effecting speed and feed changes. They may also incorporate a leadscrew for thread tapping purposes. The feed cycle often provides for fast approach, trip to normal feed, and quick withdrawal.

Each head is generally a self-contained unit and can be operated as such when setting up, but is connected either electrically, mechanically, etc., with the other machines so that it operates in unison with them—i.e. the cycle of each machine commences simultaneously with those of the others. A single press button can provide full control of the entire system, including the machines, the work transfer mechanism, swarf conveyors, etc. Because of its obvious advantages, hydraulic operation is widely employed for the machine heads.

Many firms design a machine head or heads to suit their own requirements, and then standardise the design for use on all their transfer systems. This helps to reduce costs and also makes the designing of the lines much easier. Many of the heads are little more than a welded fabrication capable of holding the various items of mechanism mentioned earlier, and are therefore produced relatively cheaply—i.e. in comparison with the more elaborate heads provided on ordinary machine tools. By keeping the width to a minimum it is possible to mount the heads closely together, thus making the line as short as possible. The width, however, is controlled by various factors, such as component length, fixture design and location, servicing, etc.

The Table

The heads are mounted on one or more sides of a long " table," the name " table " being used only because it carries the work. In actual fact, it often consists of rails, a static roller conveyor track, or a combination of both. The frame of the table usually carries the mechanism for transferring the work from station to station, and the machine heads are secured to one or more sides. The table need not necessarily be straight, although this is an ideal shape. It could be circular, U-shape, curve backwards and forward, or be of any shape to suit local conditions.

In order to machine several faces it may be necessary to turn the component through 90 or 180° during its progress from station to station, and this is done without difficulty by incorporating roll-overs in the table line. Again, it may be necessary at some stage to transfer the component to an auxiliary line or to a machine not built into the table : this is achieved by providing a turntable section allowing the component to be turned through 90°. Examples of these arrangements are given later.

For fully automatic installations, use is often made of a form of shuttle for moving the work from one position to another. These are operated by either pneumatic or hydraulic cylinders.

Work Holding

Large, flat components can often rest directly on the surface of the table, but it is generally more convenient to mount the work on some form of carrier, known by such names as a platen, pallet, jig-plate, etc. These are specifically designed to suit the component they carry, and incorporate

means for locating the component on its carrier and, often, for locating the carrier under the various machines. In addition, they are generally provided with some form of clamping device for securing the work to the carrier. The underside will be shaped to suit the type of table employed, and may be flat for riding on rollers or, perhaps, recessed to suit vee or flat rails.

Transfer Mechanism

A wide variety of transfer mechanisms are available for moving the platen from station to station. One of the most common types consists of a long circular-section " transfer bar " mounted just below the table surface and provided with projecting spring-loaded fingers or pawls (Fig. 1). The bar is given a lengthways translational movement, during the return stroke of which the pawls move all the platens on to the next station. This scheme is described in more detail later. It will be appreciated that the distance between the centres of all the machine heads must be identical, and that the stroke and position of the transfer pawls must be arranged to deliver every platen to a precise position under each machine.

An alternative to the transfer bar is to carry the pawls on a chain which is caused to move backwards and forwards in the manner of a shuttle. There are undoubtedly many other ways of obtaining this transfer movement. For instance, mechanical, hydraulic, and pneumatic operation of the transfer bars is variously encountered in different factories.

The system is interconnected with the time cycle of the machines, and interlocks or other means provided to ensure that the platens are not moved until the last tool is clear of the work, or that the spindles cannot descend until the transfer movement is completed.

Swarf Removal

Because of the continuous and high rate of production, the amount of swarf produced is generally quite considerable, and thus means must be provided for regular removal of it whilst the line is in operation. To keep the sliding ways of the tables clean, it is common practice to provide gaps in the ways so that the swarf falls below into some form of conveyor. To facilitate the direction of the chips on to the conveyor, the bed of the table may be provided with sides which slope inwards, hopper fashion. Such a scheme, used in conjunction with a vibratory-type conveyor, is described later.

Sequence of Operation

The sequence of operation is along the following general lines, although it must be realised that it may vary from factory to factory. The line is

set into operation by pressure on a single switch, this causing the transfer mechanism simultaneously to move all the components to the next machine. In some installations, clamping devices will now automatically come into operation to locate the work or platen accurately under the



Fig 1—A VIEW LOOKING DIRECTLY DOWN ON THE TRANSFER SECTION

Note the transfer bar (supported on rollers) and the angular self cleaning grooves on the table surface Below is seen part of the vibratory swarf conveyor

machine and then clamp it to the table . in others (such as that described later), the machine head incorporates means of locating and securing the platen. Next, the head commences to descend or advance at, possibly, fast approach, this dropping to cutting speed just before the tools reach the work surface.

After completion of the operation the tools withdraw, usually at a fast traverse. When the tools of the head employing the longest time cycle have withdrawn, the clamps are released (in cases where they are provided on the table), and the transfer mechanism comes into action again to repeat the cycle. All the movements are automatic and are controlled by limit switches.

The sequence described above is extremely simple, and by no means covers all the possibilities. For instance, it could incorporate a dwell period, a reciprocating motion for clearing swarf when drilling deep holes, or some other type of movement.

A Semi-automatic Installation

In many factories the output of one particular component is not large enough to warrant the installation of a fully automatic line, although it is sufficiently large to justify the employment of some special system capable of increasing production. Again, although there may be a shortage of labour, this shortage may not be acute.

In such cases it is possible to introduce a semi-automatic system, which is half-way between ordinary flow production methods and the fully automatic transfer line. The output is only slightly less than that of the latter, the installation cost is much lower, and only a comparatively small number of operators is required. Naturally, the actual scheme adopted will vary according to the type of component being produced and the quantity required, and thus no hard-and-fast rules can be stated.

The most satisfactory way to illustrate the principles of the semi-automatic transfer system is to describe an actual installation. The following information refers to a line installed for the machining of cast-iron cylinder heads for a 6-cylinder commercial engine : there are two heads per engine.

Factors Influencing the Choice of Installation

The introduction of the line was influenced by the following factors : (1) shortage of labour, (2) need for conservation of floor space, (3) the need for providing means of increasing output later, should it be necessary, (4) reducing operator fatigue, and (5) to provide for more economic production.

The machining of the cylinder head involves twenty-four operations or sets of operations, normally requiring the presence of twenty-four operators. In contrast, the present line requires only four operators. If necessary, this number could be reduced, with a slight reduction in output. On the other hand, the design of the line is sufficiently flexible to allow the number of operators to be increased in order to raise output should this be necessary. In addition, the line is so planned that machines can be added if additional operations became necessary because of modifications of the design of the cylinder head in the future.

As just mentioned, twenty-four separate machines or stations would be required if the head were machined by ordinary production methods. This would involve the stacking on the floor of at least twenty-four piles of cylinder heads, these occupying considerable floor space. In contrast, the present system necessitates stacking only at the beginning and end of the line. Further floor space is saved by the fact that the plant is much more compact than it would be if the machines were installed separately.

All the operations and tools are controlled mechanically, a feature which eliminates the " human element " and thereby reduces the chances of inaccuracies in the finished product. Finally, at no stage in the line is it necessary for an operator manually to lift a casting or exert any serious clamping effort, and thus operator fatigue is practically eliminated. When designing the cylinder head, special consideration was given to the fact that it was to be machined on this line and, as a result of collaboration between the Design and Production Departments, several slight modifications were made in order to facilitate manufacture.

The Platen

For all machining operations except the first, the casting is secured to a "platen." Basically, this comprises a suitable plate incorporating means of locating and securing the casting, and also for locating the platen under each machine. The casting is attached to No. 1 platen by two fitting bolts locating in bushed holes, whereas dowels are used for location on the other platens. The platen is located under the machines by two larger steel-bushed holes, one at each end.

During its passage along the line the platen (*a*) rides on the top of rollers and (*b*) slides on the guides of transfer tables. For the latter, the underside of the platen is recessed to a sliding fit between the guides. To prevent the collection of swarf and dirt, angular slots are provided along the table slides (Fig. 1), these having a self-cleaning effect. When on the rollers, the platen rides on the top of the ledge on each side of the recess. By this means, wear of the surfaces in contact with the table guides is reduced considerably, thereby minimising loss of accuracy due to wear.

Three different platens are required for each casting and, as will be seen later, means are provided for changing from one to another without causing any operator fatigue. When designing the platens, consideration was given to the fact that another slightly larger cylinder head was to be introduced in the future. This resulted in the provision of a pair of additional locating holes in the base so that similar types of platens can be used for both models.

Layout of the Line

From Fig. 2 it will be seen that the stations are arranged in a straight line, nearly 200 ft. long. The table linking the machines consists of

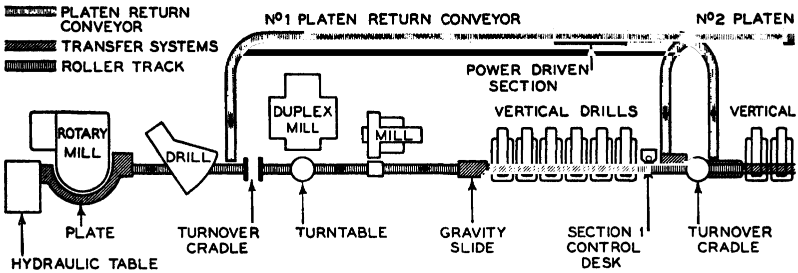


Fig. 2.—LAYOUT OF SEMI-AUTOMATIC TRANSFER LINE FOR MACHINING

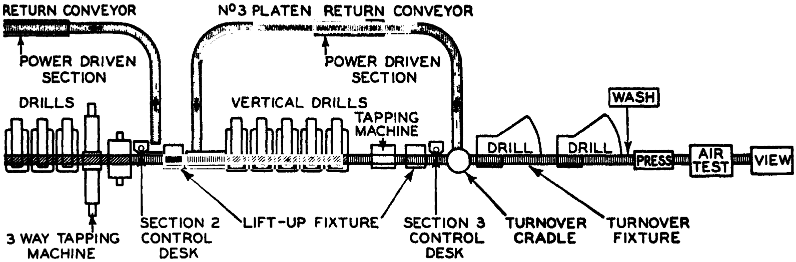
sections of static roller-track and rectangular-section rails (Fig. 1); in places it incorporates turnover and turntable sections, and lifting devices to facilitate handling.

In order to understand the reason for laying out the line in its present manner, it is necessary to consider the types of operations performed on it. Apart from preliminary facing and a few final operations such as washing, testing, and viewing, the line is concerned solely with drilling, reaming, and tapping a total of eighty-nine holes in the various faces of the head. As will be seen later, these operations are spread over three batteries of hydraulically operated drilling heads: except for two machines, they are all of identical design.

Machine Design

Very careful consideration was given to the design of these machine heads to make them as adaptable as possible—i.e. to suit any future changes in the cylinder head. Each incorporates a multi-spindle attachment enabling as many holes as centre distances will allow to be drilled, reamed, or tapped simultaneously. By means of pick-off gears the speeds and feeds can be adjusted to suit any changes that may be necessary in the future. For setting purposes, each head can be operated independently and has its own cycle which may include quick approach, trip to cutting feed, dwell, and quick withdrawal. All heads in the same battery are interconnected so that the cycle is initiated in unison.

It will be appreciated that the time cycle of the various heads differs according to the depth and diameter of hole, and the type of operation being performed—i.e. drilling, reaming, or tapping. For this reason, each head operates on its own particular time cycle, which ends with the head in the raised position. The overall time cycle for the entire battery is that of the head requiring the longest time cycle—i.e. three minutes. Thus, heads employing a shorter time cycle " idle " in the raised position until the last machine has finished its cycle of operations and returned to the raised position. When this occurs, the transfer bar mechanism is set



CAST-IRON CYLINDER HEADS FOR A 6-CYLINDER COMMERCIAL ENGINE

into motion to move each platen to the next head. As soon as this movement ceases, all the heads simultaneously feed downwards and commence the next 3-minute cycle. The cycle is initiated by pressure on a switch which holds automatically until it is overridden by another switch.

Master Guide Bars

To permit easy movement of the platens, a certain amount of " play " between the table slides and the guides on the underside of the platen is unavoidable. Thus provision must be made to ensure accurate location of the platen under each head. For this reason, a large-diameter circular-section master guide bar is provided on the sides of the heads, each guide bar incorporating a spring-loaded stripper (Fig. 3). As the head descends, the rounded end of the guide bars enter two steel-bushed holes in the platen and then two bushed holes in the table, thus accurately locating it in position. Continued downward movement brings the end of the spring-loaded stripper into contact with the platen, holding the latter firmly against the table slides while the head descends still farther to allow the tools to perform their work. When the head retracts upwards, the tools clear the work first : as the guide bars rise, the strippers continue to maintain pressure on the platen until just before the ends of the bars leave the holes, when they themselves rise with them.

Speeds and Feeds

It was mentioned earlier that the longest " machine cycle " is three minutes. This rate ensures the best tool " life." However, should it be necessary to increase the rate of output, this can be achieved without any difficulty by raising the speeds and feeds, where necessary, throughout the line. In effect, this means increasing the speeds and feeds of those operations which take the longest time cycle, and by introducing tungsten carbide tooling to reduce the longest operations to a lower time cycle.

Because of the efficiency of the transfer line, and in order to maintain

balanced production with other departments, it has been necessary to use speeds and feeds that are lower than those normally employed. As a



Fig. 3.—THIS CLOSE-UP VIEW OF A MACHINE HEAD CLEARLY SHOWS THE MASTER GUIDE BARS FOR LOCATING AND CLAMPING THE PLATEN

Below the end of the platen is seen part of another bush which will be used when larger components are machined at some future date.

result of this, tool life has increased amazingly, effecting considerable economies in both tool costs and resetting times.

As will be seen later, the need for using spanners has been avoided by the provision of quick-action clamping devices.

Transfer Mechanism

On the first and last sections of the line the platens are moved manually by the operator. In the cases of the three groups of drills, however, they are moved from machine to machine automatically by transfer bars, one being provided for each battery. These consist of long bars provided with a number of spring-loaded pawls (Fig. 1) so designed that they are pressed back into recesses in the bar as they pass under the platen, and then spring upwards when they are clear. By means of a small motor and chain drive slider the bar is given a reciprocating movement with a stroke long enough to transfer the platens to the next machine. The machines of each group are spaced the same distance apart.

Swarf Removal

A considerable amount of swarf is soon produced, and thus it is essential to provide some means of automatically disposing of it. To do this, the sides of the interior of the conveyor track slope inwards to direct the falling swarf into a long narrow trough running the length of each battery of machines (Fig. 1). This trough is, in fact, a vibrating conveyor which is so designed that each vibration causes the contents to " jump " a short distance along the trough. In actual fact, the vibrations are so rapid that the swarf flows forward in a continuous stream. An important feature of this type of conveyor is that it can be set to cause the swarf to flow " up-hill." Four such conveyors serve the line—i.e. one for each battery of drilling machines—and these all deliver into an inclined conveyor discharging into a large storage bin which is emptied at intervals.

Operation Sequence

From the following detailed description of the operations performed along the entire line, it will be seen that all the important requirements mentioned at the beginning of this chapter—particularly those referring to the elimination of operator fatigue—are fully met. In addition, many of the items provide an extremely useful study of modern production practice.

The First Operations

The castings are brought to the beginning of the line by a fork-lift truck and the load deposited on an hydraulically operated adjustable table situated close to the first machine. By movement of a single handle the height of the table is adjusted to bring the top layer of castings level with the machine table so that they can be transferred to it without any need for lifting—i.e. by sliding them. As the operator works his way through the castings, the table is raised to maintain the correct level of the top layer.

The first operation is concerned with continuous milling of the top and bottom joint faces—i.e. the top and bottom faces of the castings. Cast

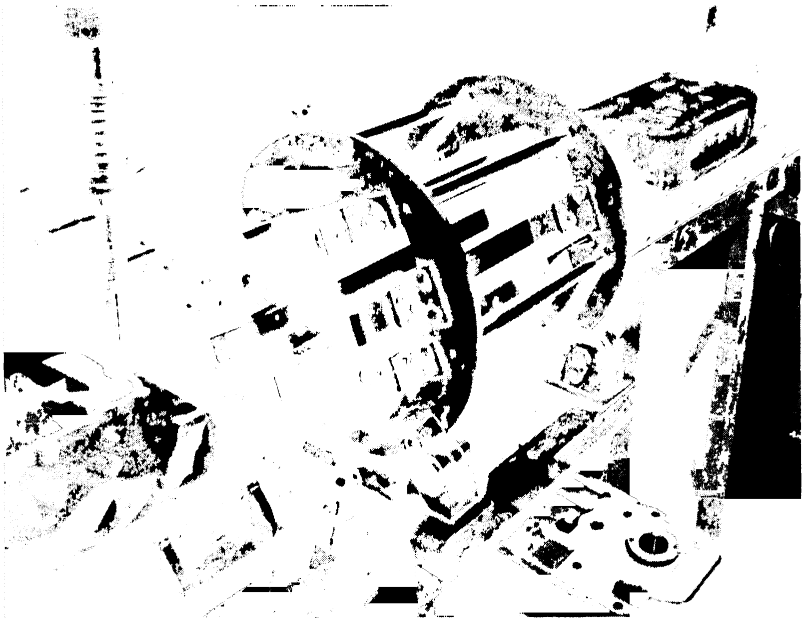


Fig. 4.—THE FIRST TURNOVER CRADLE, WHICH BRINGS THE CYLINDER HEAD INTO ITS CORRECT POSITION FOR MOVING ALONG THE LINE, I E WITH THE PLATEN UNDERNEATH

Below the cradle is seen the end of No. 1 platen return conveyor.

on one face are three small location pads, and by locating all machining operations from these it is possible to guarantee that the complicated internal water passages, as well as the external surfaces and holes, are in correct relationship with each other.

The milling machine has two horizontally arranged face mills, one for roughing and the other for finishing. Below them is a rotating circular table carrying four quick-loading fixtures. Two of these are designed to hold the casting when rough- and finish-machining one joint face, and the others for machining the second face.

Locating from the three pads, the casting is secured in its fixture and is carried under the first (roughing) cutter, and then on to the second spindle (set to cut slightly lower than the first) which finish-mills the face It is then reversed and transferred to an empty fixture in front of it, in which it is located from the previously machined face, and is carried once more under the two cutters to rough- and finish-machine the second side : this fixture is identical with the first, except that it raises the casting slightly higher. The fixture left empty when transferring the casting for



Fig 5—THE TURNTABLE FOR DIRECTING THE CYLINDER HEAD INTO THE FIXTURE OF THE DUPLEX MILLING MACHINE FOR OPERATIONS ON THE SIDE FACES

machining of the second side is then loaded with an unmachined casting taken from the hydraulic table. By this means, continuous milling is achieved with very little effort by the operator.

Turnover Cradle

As removed, the casting is slid on to a static roller track or "table" arranged at the same height as the machine table, and pushed by hand to an adjacent radial arm drill, where two service holes are jig-drilled and tapped. The bolts for these are accurately machined to suit two bushed holes in the platen, thus ensuring very close location of the platen on the castings. The platens are obtained from the platen return conveyor seen on the right of the drill (Fig. 4): this conveyor is described in detail later.

At this stage the platen is on the top of the casting, and it is now necessary to reverse the assembly so as to bring the platen to the bottom —i.e. to rest on the table. The combined weight of the platen and casting is fairly considerable, and in order to enable the operation to be performed without undue fatigue a turnover cradle is incorporated in the table

(Fig. 4). The assembly is merely pushed into the cradle and the latter rotated with very little effort to bring the assembly into its correct position. It is then pushed along the rollers to the next station.

Turntable

This is concerned with milling the two long sides—i.e. the manifold cover face and the back cover face. When in the loading position, the machine table practically touches the roller track, and thus the need for manual lifting is avoided. In order to present the two sides to the cutters it is necessary to turn the casting through 90°, and to allow this to be done with minimum effort a turntable (Fig. 5) is incorporated in the section immediately facing the milling machine. To load the machine, the table section is rotated through 90° and the casting pushed into the empty fixture.

The design of this fixture is interesting because it typifies the precautions taken throughout the entire line. To prevent any chance of mistakes, the clamping and location arrangements are interlocked so that it is impossible to secure the clamp unless the locating pins are correctly in position. In the base of the fixture are two retractable large-diameter pins which locate the casting by entering two of the bushed holes in the base of the platen. The design is such that until these pins are fully entered, the tip of the clamp cannot enter its mating recess.

In order to provide the necessary strength, the clamp is of fairly substantial proportions and, consequently, is rather heavy. To minimise fatigue when loading and unloading, it is accurately counterbalanced so that little more than finger pressure is required to raise and lower it. The clamp is locked by rotation of a star-wheel, thus avoiding the effort of using a spanner.

The machining cycle is fully automatic, and when the operation is completed the table comes to rest close to the track, so that the casting can be slid back on to the turntable. The latter is then rotated through a further 90° to bring the platen in line with the track, and the casting pushed on to the next machine to mill the two short ends.

As before, when in the loading position the machine table practically touches the roller track, and the casting can be slid into the fixture with very little effort. This time it is not necessary to turn the casting, because it already lies in the correct position. The operator locates the casting by moving a small lever to raise two pins which enter the holes in the platen. Movement of another lever then operates a cam clamping device to secure the casting. As on the previous machine, the two movements are interlocked to prevent clamping unless the casting is correctly located.

The Transfer Line

The next part of the line consists of two rectangular-section rails which dip at a steep angle to bring the casting down to the level of the



Fig. 6.—THE COUNTERBALANCED LIFTING DEVICE WHICH FACILITATES REMOVAL OF NO. 2 PLATEN AND SUBSEQUENT FITTING OF THE ANGULAR NO. 3 PLATEN SEEN ON THE RIGHT

battery of six machines forming the first section of the transfer line proper. The platen slides rapidly down the rails, gaining sufficient momentum to carry it into contact with the first pawl on the transfer bar. From here onwards, the castings are moved from machine to machine automatically until they have passed under all the heads in the first battery. The drilling, reaming, and tapping operations are performed automatically, the castings moving on to the next head at the end of each cycle.

After the casting leaves the last machine of the first group of machines it is necessary to reverse it in order to machine the face at present at the bottom. This involves fitting another (No. 2) platen, reversing the casting, and removing No. 1 platen. These operations are performed with the aid of equipment built in the next section of the table.

As the casting leaves the last machine it also leaves the transfer bar. The operator now picks up a No. 2 platen from the end of No. 2 platen return conveyor and places it on top of the casting, where it is located by two dowels just drilled and reamed by the preceding machines. This platen (see Fig. 6) incorporates two clamps which enter cored holes in the casting to secure the latter to the platen.



Fig. 7.—THE SECOND TRANSFER SECTION, COMPRISING FIVE VERTICAL AND ONE HORIZONTAL DUPLEX HYDRAULIC DRILLING MACHINES AND ONE THREE-WAY MULTI-SPINDLE TAPPING MACHINE

The casting (and two platens) is now pushed to an adjacent turnover cradle built into the table, where it is reversed to bring No. 1 platen uppermost : the two securing bolts are then removed. This particular fixture can be swivelled as well as turned over, and it is now swivelled through 90°. This permits No. 1 platen to be pushed on to the end of No. 1 platen return roller conveyor, which returns it to the head of the table for reuse. The first section of the return conveyor slopes downward, allowing the platen to gain sufficient momentum to carry it to the foot of a rising power-driven section. This raises it to the top of another gravity roller section, down which it rolls to feed the first turnover cradle (Fig. 4).

After removal of No. 1 platen, the lid of the cradle fixture is closed and the unit swivelled through 90° to bring the casting in line with the table. The casting is now in the correct position for the next group of operations—i.e. No. 2 platen is at the bottom. All the above work is done by the operator in charge of the first battery of machines.

By pushing the casting for a short distance along the table slides it reaches a position where it is picked up by the transfer bar serving the second group of machines (Fig. 7). As before, the casting is then automatically transferred from machine to machine. This second group

comprises five vertical drills, one horizontal opposed-head drill, and one three-way tapping machine, all fitted with multi-spindle attachments.

Machining the Angular Holes

The third group of machines is concerned with drilling, reaming, and tapping certain holes which lie at an angle of 20° to the joint face. This could be done by using heads set over at an angle of 20°. This scheme, however, possesses the disadvantage that any future modifications in the design of the casting would involve expensive and lengthy alteration of the machines. In addition, the machines would have to be of special design instead of conforming to the standard design employed throughout the other groups.

For this reason it was decided that it would be more economical to employ machines of standard vertical-spindle design and to tilt the work by using platens having an angular top face (see Fig. 6). Thus in the event of any future modifications, or the introduction of cylinder heads of different design, the only major alteration necessary would be to provide new platens.

Thus, when the casting leaves the transfer bar after the last machine of the second group it is necessary to replace No. 2 platen by an angular-face No. 3 platen. To do this the casting is pushed under a " lift-up " fixture astride the conveyor track (Fig. 6). The two clamps are loosened and the casting raised, leaving No. 2 platen on the track, from where it is transferred by hand to the adjacent No. 2 platen return conveyor to be returned to the beginning of the second group of machines for reuse ; the design of this conveyor is similar to that of the No. 1 platen return conveyor described earlier.

With the casting still suspended, a No. 3 platen is removed from the end of the adjacent No. 3 platen return conveyor and placed on the track, under the casting. By means of a foot-operated control the operator is able slowly to lower the casting on to the platen, guiding it with his hands, both of which are free. The casting is then secured by clamps forming part of the platen, as in the case of No. 2 platen. This change-over of platens is effected during the cycle by the operator in charge of the second batch of machines, who then pushes the casting along the table until the platen is engaged by the transfer bar serving the third group of machines.

Final Stages

The last machine in this group is a multi-spindle tapping machine, and when the casting leaves it, No. 3 platen is removed with the aid of a lift-up device similar to that just described (Fig. 6). It is then placed on No. 3 pisten return conveyor and returned to the end of the second group of machines. This is done by the operator in charge of the third group of machines.

The table now changes to the form of a roller track, on to which the

component is lowered and then moved along to a turnover cradle, where it is rolled over in order to remove the swarf from the internal passages and the holes. Whilst in this cradle, an internal wire-brushing operation is performed with flexible drive equipment.

The next operation is concerned with drilling and reaming three holes in each end of the casting and then inserting plugs in them. To do this, a turnover cradle is provided in the table to allow the casting to be turned to present first one end, and then the other, to the drill. This fixture is actually attached to the side of the drill table, at the same level as the rollers.

After completion of the second end, the cradle is rotated through 90° to permit the casting to be pushed along the rollers to a washing machine During its passage through this it is washed by high-pressure jets of hot alkaline solution. The use of hot liquid has two advantages, (1) it improves the efficiency of the solution, and (2) the heat gained by the casting helps it to dry very quickly, so that it is dry enough to handle by the time it reaches the next station.

After leaving the washing machine, the casting is pushed along the rollers to a foot-operated hydraulic press, where three copper injector sheaths are pressed into position. This is done without removing the casting from the track.

From here the cylinder head is moved to an adjacent station equipped for testing the porosity of the casting. All water passage faces are sealed by quick-action rubber-faced clamps which, at two points, incorporate provision for the entry of compressed air. For the test, the casting is immersed in a vat of hot water which, to prevent rusting, incorporates an inhibitor.

After removal, the casting passes for viewing at the last station on the line.

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Chapter XXIII

DEEP-HOLE BORING

THE drilling or boring of long relatively small-diameter holes presents special difficulties which prevent the employment of ordinary drilling methods. Spade drills (Fig. 6, Chap. V) were originally used for this work, but the lack of accuracy, poor quality of finish, and short tool life, coupled with the slowness of the operation due to the need for constant withdrawal of the drill in order to clear the swarf, made them far from satisfactory. Also, in spite of the provision of internal passages to conduct coolant to the tip, overheating still occurred.

Theoretically, the use of any form of drill is unsound for producing holes of, say, 2 in. diameter and above because the cutting speed of the edge varies over its length. The maximum speed is at the outer tip, this decreasing as the centre is approached until, at the very centre, the speed is so low that the drill is forced into the metal without cutting freely.

TREPAN BORING

One solution to this problem lies in the use of "trepanning," an operation long employed for producing large-diameter holes in plate, but only recently adapted for machining bores in solid metal. As a guide to the success of this operation it may be mentioned that, under ordinary production conditions, an accuracy of ·001 in. for taper and ovality per 40-in. length is readily maintained.

Because of the different classes of work involved, many firms design their own equipment to suit their particular requirements. However, the basic features are common to all machines, and these are briefly surveyed below. This information is later amplified by more detailed descriptions of equipment actually in use.

The Trepanning Head

Cutting is done with a hollow head (Fig. 1) carrying one or more tungsten carbide tools, the head being secured to the end of a long hollow bar. The tools produce a bore of slightly larger diameter than that of the head and bar, and thus there is an annular space between them. In some machines this is used for feeding high-pressure cutting oil to cool the tips and wash the chips away, the oil and chips returning to settling tanks and filters via the hollow cutter head bar; on others the reverse applies,

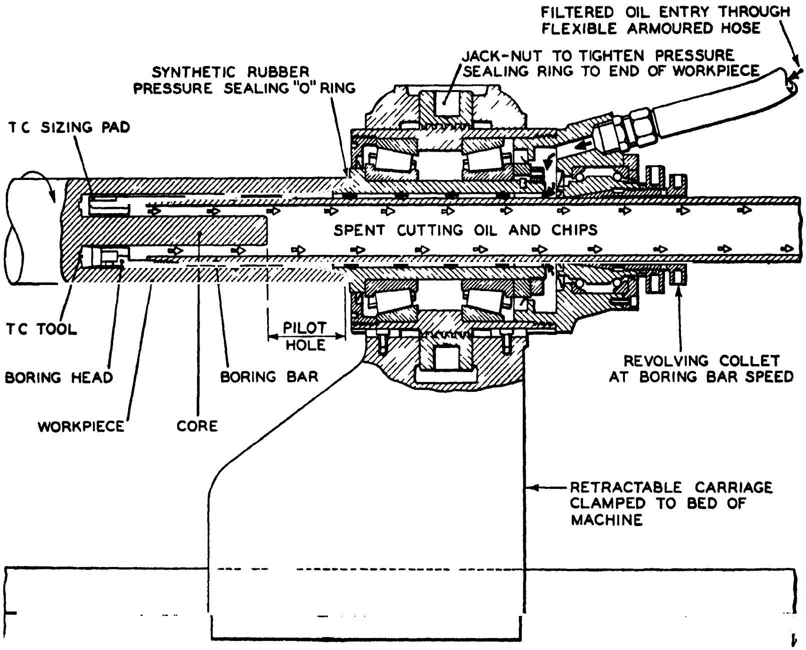


Fig. 1.—Work support and cutting-oil pressure head for a trepan-boring machine

the oil entering along the hollow bar, and the oil and chips returning along the annular clearance. It will be obvious that in order to prevent the passages becoming choked (1) the chips must be small and of suitable shape, and (2) the pressure and quantity of the oil must be sufficient to keep the chips moving freely.

To a large extent trepan boring is only possible because of the availability of the tungsten carbides, because even the best of tool steels have a very short life under the extremely arduous conditions encountered in machining deep holes. The tools are positioned to cut an annular recess so that some of the waste metal is produced as a core of metal which passes up the centre of the hollow bar and can be used for other purposes.

Some machines are designed to cut from one end only, whilst others are arranged to bore from both ends simultaneously, the choice depending largely on the length and shape of the work. Again, in some instances the work revolves and the cutters are stationary, while in others the cutter also rotates, but in the opposite direction.

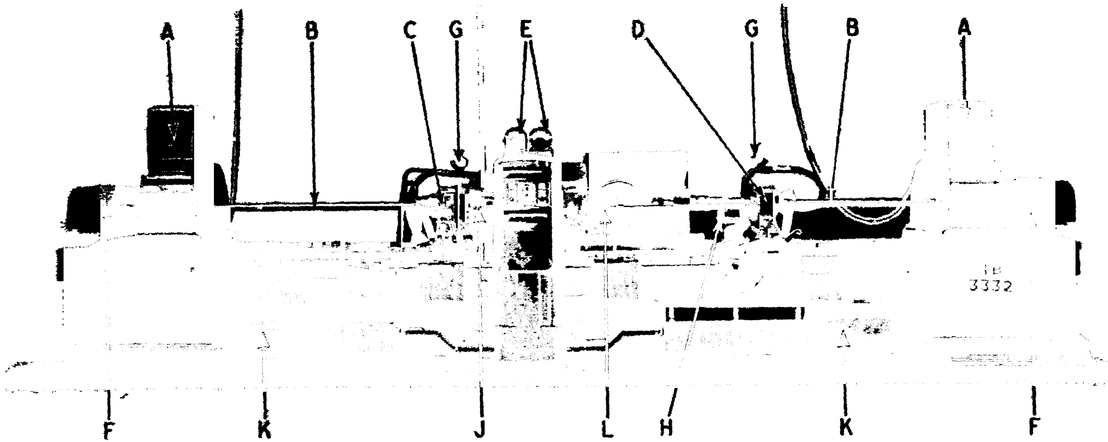


Fig 2.—GENERAL VIEW OF TREPAN BORING MACHINE ANNOTATED TO SHOW THE MAIN FEATURES

A = 25 h p driving head
B = Boring bar
C = Coolant sealing head
D = Coolant sealing head and running steady
E = Ammeter—load on driving head motor
F = Chip-examination point
G = Coolant oil pressure gauge
H = Work loading rest
J = Chuck cover
K = Coolant oil settling tank
L = Work (rear axle casing)

The Machine

The machine (Fig. 2) is generally designed to suit the particular workpiece involved, which may be a small-diameter part 40 ft. or even more in length.

The cutting forces are considerable, and thus every part of the machine must be designed to ensure maximum rigidity: vibration will adversely affect the smooth cutting action of the highly stressed tools. Also, the machines are generally of considerable length and thus, should any deflection occur, the accuracy of the bore will be affected. The importance attached to this may be gauged from the fact that, to reduce chances of deflection or vibration due to poor foundations, one machine was mounted on a concrete bed weighing 120 tons. For reasons of accuracy, correct alignment of the various movements is absolutely essential.

The work-holding equipment must be specifically designed to suit the component. In some instances long lathes have been adapted for smaller single-end types of trepan-boring work, and in such cases it is often possible to grip one end in a three- or four-jaw chuck of standard design; the outer end is supported in a steady in a manner similar to that employed for the normal boring of deep holes. Should the work be very long or heavy, it will be necessary to provide intermediate rests or steadies along its length.

If boring is from both ends simultaneously, the work-holding equipment is in, or near, the centre of the machine bed. As a rule it is rotated by a self-contained variable-speed motor-driven unit. The power must be adequate to deal with the rate of chip removal involved, and may necessitate the use of motors of 100 h.p. or even higher.

The machine incorporates one or two heads for supporting and feeding the cutting tools and bar. A large-capacity oil pump is necessary for each head, and also an efficient filtering system to remove every trace of chips and fine swarf from the oil before it is recirculated. In order to keep the rise in temperature of the oil under control, the settling tanks should be of generous proportions. To prevent leakage, a carefully designed rotating seal will be required at the point where the high-pressure oil enters the annular space between the cutter bar and the workpiece. If the cutters revolve, means for rotating the bar and head will be necessary.

Requirements for Successful High-speed Trepan Boring

To ensure successful trepan boring the following requirements are essential:

(1) The machine must be absolutely rigid and accurately aligned.

(2) Tungsten carbide tools and rubbing pads *must* be used.

(3) The chips must be short and of correct shape in order to permit free removal by the cutting oil.

(4) The speed and feed combination must be carefully planned to suit the particular cutting tool in use.

(5) A plentiful supply of the correct grade of cutting oil at high pressure. In general, an oil with good lubricating properties under conditions of high bearing pressure is necessary to meet the requirements of the " pressure " and " sizing " pads. A 2 per cent. sulphur base oil such as Frapol 99B will be found to be suitable in most cases.

(6) The drive must be of sufficient power to ensure smooth, uninterrupted cutting.

Production Data

It is not possible to lay down any hard-and-fast rules, or give any standard figures, for the above because they will vary with such factors as material analysis, diameter and length of the bore, etc. A useful guide is, however, provided by the following information relating to work carried out under actual production conditions.

The first example concerns the trepan boring of a 3-in. diam. by 23-ft.-long hole in nickel-chrome-molybdenum steel. The operation occupied 53 mins., and the diameter of the core removed was 1·6 in. Boring was from one end, and only the work rotated. The peripheral speed of the latter was 570 ft. per min., and the feed was 0·007 in. per revolution.

Under the same conditions, other bores of similar length have been machined in the same material in 34 mins., using a feed and cutting speed of 0·0098 in. per revolution and 670 ft. per min. respectively. A 2½-in.-diam. by 30-ft.-long bore in 0·4 per cent. carbon steel was produced in 57 mins., using a feed and cutting speed of 0·0075 in. per revolution and 550 ft. per min. respectively.

Cutting Tool for Trepan Boring

Figs. 3 and 4 show a tool developed for trepan boring a 2·440-in.-diam. by 43-in.-long hole through rear axle casings forged in EN 16 steel (45

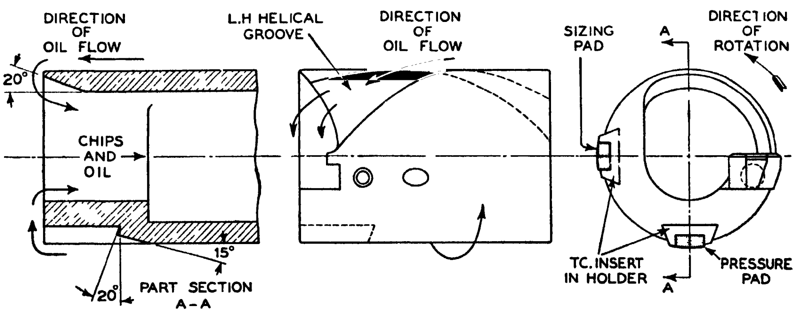


Fig. 3.—A CUTTING HEAD FOR TREPAN BORING

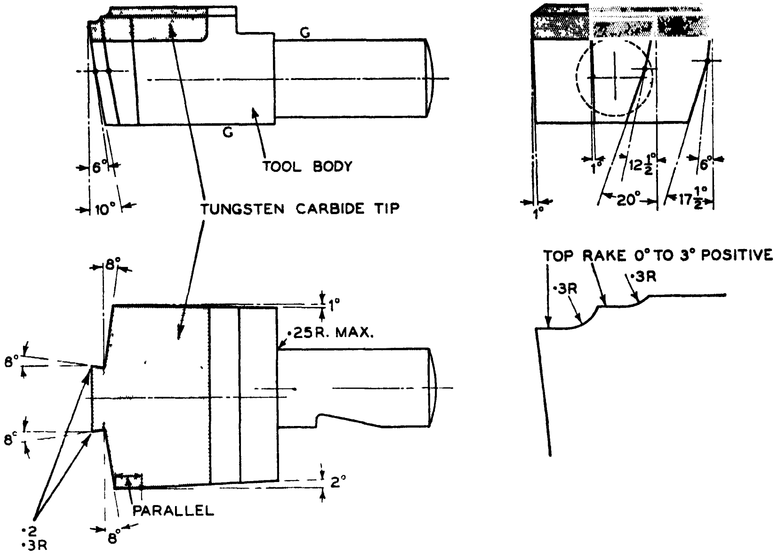


Fig. 4.—DETAILS OF A TUNGSTEN CARBIDE CUTTING TOOL FOR TREPAN BORING

tons tensile, 255–207 Brinell). It has a relatively narrow width (0·708 in.) and thus the variation in cutting speed between the inner and outer edges is acceptable, and free-cutting conditions exist over its full width. Because a narrow tool is employed, a central core of waste metal is produced in addition to the chips.

The cutter is held in a recess provided in the side of the front end of a 3½ per cent. nickel high tensile steel head (Fig. 3), and is arranged with its cutting edge radially disposed to the line of the bore. In order to break the full width of the chip into three pieces, the cutting edge is divided into three sections, as shown in Fig. 4. As mentioned earlier, it is essential to keep the chips to a size small enough to permit easy removal by the coolant, and for this reason each of the three cutting edges is provided with a ·015-in.-deep by ·060-in.-wide chip breaking step. The design is such that short curly chips approximately ⅜ in. long are produced. The tool projects slightly above the diameter of the head, thus providing the annular clearance through which oil can flow.

" Pressure " and " Sizing " Pads

Two pads inserted with tungsten carbide and pressed into suitable recesses (Fig. 5) are also provided on the head. One, situated diametrically opposite the tool, is a " sizing pad " which projects slightly above the diameter of the head so that the overall diameter from the top to the

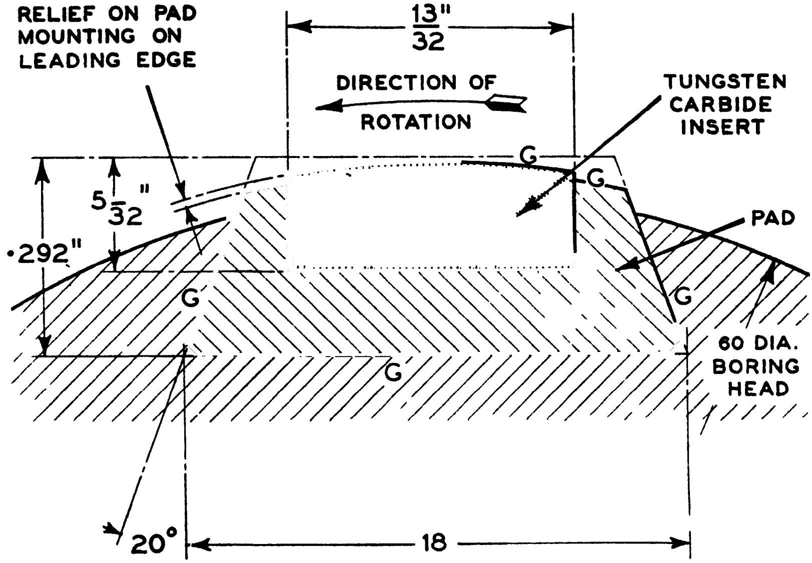


Fig. 5.—DETAILS OF THE TUNGSTEN CARBIDE "PRESSURE" AND "SIZING" PADS FOR A TREPAN-BORING HEAD

The pad is made from a 60 per cent. carbon steel, and the tungsten carbide tip is brazed to it.

outer tip of the cutting tool is 2·440 in.—i.e. the diameter of the required bore. The cutting edge of the tool is, naturally, slightly in advance of the front edge of this, and the other, pad. As the name implies, this pad maintains the correct bore diameter by resisting side thrust due to the cutting action of the tool. The second pad, known as the "pressure pad," supports the head against downwards deflection due to the considerable cutting forces.

When considering the functions of these two pads it is necessary to remember that the bore is larger than the diameter of the head, and thus the latter would "float" if not supported in the above manner. Both of these pads rub against the bore and are therefore subjected to considerable abrasion; any other material than tungsten carbide would quickly be worn away, resulting in inaccurate, badly finished holes.

At the front end of the head is a helical groove which directs extra coolant oil to the tips of the tool. The head is secured to its long hollow bar by a sturdy square thread. To facilitate accurate starting of the tool, a short length of the hole is accurately pre-bored on another machine to act as a pilot.

The trepan-boring operation is performed on a 23-ft.-long machine.

It has a 25-h.p. motor-driven boring head at each end, and in the centre is a three-jaw self-centring chuck driven by a 15-h.p. motor. One end of the axle casing is inserted in the long hollow spindle of the chuck and the jaws then tightened on to previously machined external surfaces. The other end is supported in one of the pressure heads, which also acts as a hollow running centre.

The normal procedure when trepan boring is for the work to revolve and the tools to remain stationary. However, in this particular case—due to the impracticability of running the work fast enough—both the work and cutters revolve, in contra-rotating directions, the work at 116 r.p.m. and the tool at 327 r.p.m. : this gives a cutting speed of 282 ft. per min. The feed is 3·42 in. per min., which is equivalent to 0·0077 in. per revolution.

High-pressure Oil Supply

As already mentioned, an essential requirement for success is the provision of an adequate high-pressure oil supply to remove the chips from the interior of the bore. On this machine the delivery rate and pressure are 50 gallons per min. and 125 lb. per sq. in. respectively. The oil enters each bore through a special seal (Fig. 1), travels along the annular space between the bar and bore until it reaches the cutting head. Here the helical groove mentioned earlier directs it on to the cutter. The only way of escape is to return up the interior of the bar—i.e. along the annular space between the core and the interior of the bar. It will be appreciated that the internal annular space is relatively small, and this emphasises the earlier statements that a plentiful supply of high-pressure cutting oil, and the maintenance of correct chip size and shape, are essential for free removal of the swarf.

In addition to the chips, small particles of steel are also produced, and it is very important to prevent their recirculation with the oil supply because they are likely to jam between the pads and bore, causing a bad finish or even tool breakage. Thus, as the oil leaves the end of the hollow bar the chips are first strained off. The oil, and fine swarf, then passes to a second tank, where much of the remaining solid matter settles. From here the oil passes through a magnetic filter which removes even the finest particles of steel. In order to keep the oil temperature as low as possible, the tanks are of particularly large dimensions.

PIERCE BORING

An alternative method of machining long holes in solid material is that known as "pierce boring." In most respects the operation is similar to trepan boring, except that the tool is designed to cut the waste metal completely into swarf—i.e. no core is produced. The following

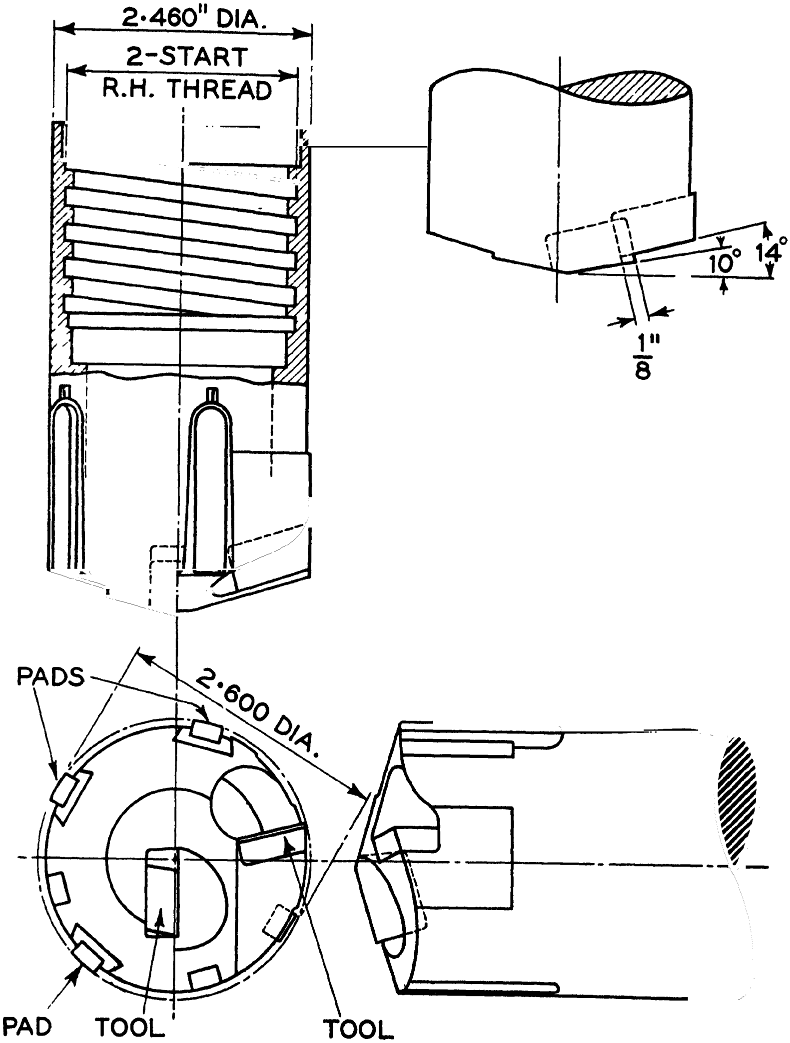


Fig. 6.—A TOOL DEVELOPED FOR PIERCE BORING

data refers to the pierce boring under production conditions of a $2\frac{1}{2}$-in.-diam. hole through a 22-ft.-long nickel-chrome-molybdenum forging.

To do this, two cutters (Fig. 6) are arranged to cover the entire radius of the hole, the width of the inner cutter being such that it slightly overlaps the centre of the hole and also the inner edge of the other cutter. It will also be noticed that one cutter is set slightly in advance (axially) of the other. Each cutter has a 5° positive top rake and a front clearance of 6°. From Fig. 6 it will be seen that the cutters are shaped to give drill-like tip to the head, an entirely different arrangement from that described earlier. A 0·020-in.-high chip-breaking step is provided approximately $\frac{1}{16}$ in. behind the cutting edge. To support and centralise the head, three equally spaced tungsten carbide pads are provided.

Only the work revolves (600 r.p.m.), and the cutters are fed from one end only at a feed of 3–5 in. per minute : the workhead is driven by a 100-h.p. motor. The piercing time per bore is 57–95 minutes. The cutting oil is delivered at a rate and pressure of 50 gallons per min. and 300 lb. per sq. in. respectively. Two magnetic filters are incorporated in the cutting oil filtration system.

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